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GEOPHYSICS

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THE FUTURE OF GEOPHYSICS*

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The petroleum industry may well take pride in the fact that it stands today in a position, shared with few others, of being able to supply easily whatever demands may be made upon it by reason of the present national defense program; and at the same time, can assure the nation that its future supply of oil is insured by a proven domestic reserve greater now than at any time in the past.

Geologists, geophysicists, and all others concerned with the exploratory activities of the petroleum industry, must of necessity be more concerned with future possibilities than with present realities. We are quite justified in congratulating ourselves upon our present accomplishments, but only because past successes enable us now to look ahead to a difficult but orderly exploration program, rather than a frenzied, inefficient scramble for immediately needed oil.

I like to think of the exploratory activities of the industry as the expression of its instinct of self-preservation. The continued existence of the industry is dependent upon our success in finding today the oil of tomorrow. It follows that there will be no appreciable change in the magnitude of exploration activity, whatever form it may take, until that yet far distant day when no then-known exploration technique is economically applicable to the finding of those fields remaining undiscovered. We all may hope, and I may be permitted to believe, that the end, when it comes, will not be far short of the ultimate end point when all oil fields at producible levels have been discovered.

Obviously, the techniques of exploration must continue to improve or expand, and the art of applying those techniques must improve if the future discovery rate is to be kept on a par with that of the present.

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Improvements there certainly will be, expansion is probable; but I believe that the greatest advances in the art of exploration in the near future will come through the more effective application of the now existing techniques of geophysical prospecting. Lacking that hypothetical being, the geophysicist of the future, who will possess all the abilities of both our professions, it is necessary that the geologist and the geophysicist learn to complement each other's efforts to a degree now only approached.

It is often true that an individual's faults and his virtues are but different expressions of the same character trait. I admire my friend who is strong-minded; but I dislike the man who is simply bullheaded. So it is with us, as professional men. The really great geologist of today, or of tomorrow, is the man whom DeGolyer has so well described as the "speculative geologist" the man who can take a meager number of facts and, by an inspired generalization, point out an area of great possibilities. Yet that very ability to generalize, if not carefully controlled, can lead the same individual to condemn an extensive area because of the lithological characteristics of the formations penetrated in a few scattered dry holes. The geophysicist, knowing from his seismograph work, that some physical properties of the section can, and do, change rapidly over a relatively short distance, naturally objects. Similarly, the geologist must sometimes feel that the geophysicist's only criterion of a favorable area is "can reflections be obtained?" and may feel that the geophysicist would just as soon map an igneous sill as an oil sand. Furthermore, the geologist must sometimes become impatient with the geophysicist's reluctance to commit himself to a definite "picture" based on data whose probable error is great.

Since no oil fields will be discovered in an area never explored, and since inaccurate geophysical work may be worse than none at all, I believe we may reasonably say that the best team of the future will be an optimistic geologist and a pessimistic geophysicist—pessimistic in the sense that he will scrutinize his results with care and refuse to allow himself or others to consider them to be better than they are.

In my opinion, domestic seismic activity will continue for at least five years at about the same level as at present, that is with between 150 and 200 crews in the field. How shall they be profitably employed? Undoubtedly we shall continue to resurvey old areas for minor structures. Work of this type is proving very successful in Central Oklahoma. It is encouraged by the accurate data now obtained at reason-

able cost, and by economic considerations. As the production of wells in an old area decreases, there is less difficulty in obtaining a fair allowable for new wells, and so more incentive to drill them. Naturally, the companies who will profit most from such work are those who have already made dependable widespread surveys of the areas concerned, rather than those whose past efforts have been confined to spot shooting in "hot" areas. Just as the sub-surface work of the geologist is never finished, so the work of re-examining the seismic picture of an area need never come to an end.

It is reasonable to expect that a considerable part of the much surveyed Gulf Coast area will be seismographed once again to map deeper horizons. This can be done with only minor modifications of the present technique. Certainly, the situation now existing should be corrected. I refer to the fact that the average depth to which the Gulf Coast has been seismically surveyed is less than the depth of many wells now being drilled. In planning a program of deeper exploration, one fact should be kept in mind. As the depth to a reflecting layer increases, the accuracy of the dip shooting method decreases, and the resolving power of the correlation method also decreases. These physical phenomena should please both the structure-minded and the trap-minded geologist. The former may be assured that the structures discovered will show ample closure; the latter that the program will delineate major faulting, unconformities, and regional features which will afford material for speculation and possibly call for revision of present ideas.

It seems certain that much of the seismic work of the future will be directly concerned with the location of stratigraphic traps. This statement may easily be disproved by simply defining a stratigraphic trap as one having no association with structure. However, if we use the term, as is commonly done, to include such accumulations as East Texas, then it cannot be said that stratigraphic traps are never associated with structure. A similar comment was made two years ago before this group by F. M. Kannenstine, then President of our Society. I prefer to think of a stratigraphic trap as one in which the accumulation is limited in at least one direction by something other than structural relief. A sand lens would then typify a pure stratigraphic trap. A pinch out of a reservoir sand on a structural nose would also be considered a stratigraphic trap of a less perfect type. Certainly, such noses can be contoured by the geophysicist, and the geologist may be able to state with considerable certainty that a pinch-out is to be expected.

Actually, the program should be reversed, the speculative geologist may indicate a zone in which a pinch-out of a possibly productive sand should occur. The geophysicist may then look for structure. Neither, at present, can be expected to indicate with certainty the exact point up-dip at which the pinch-out occurs, or the exact location of the water line down-dip, although it is conceivable that even this may sometimes be possible. The aid of the exploratory drill will usually be needed, but it is also needed to locate flank production on salt domes. It is not of record that this fact deterred us from using geophysical methods to locate such salt domes. The Coalinga Nose field and the similar but smaller East Coalinga field of California are typical examples of the type of trap discussed above. The discovery of the latter resulted directly from a geological surmise followed by careful geophysical work which located the nose.

The application of geophysical work just discussed is mentioned first because it not only can, but has been used. Other applications of the seismic method to the location of stratigraphic traps can be suggested. Up-dip convergence of the seismic horizons bounding a section known to contain productive zones, may well point to the approximate location of a pinch-out. It is easy to depict a hypothetical case of this sort in which the pinch-out could be indicated with fair accuracy.

The geophysicist should be encouraged to speculate with hypothetical cases of this sort, the geologist is well advised to join with him. I believe that both would profit also by studying together the subsurface picture of a number of known stratigraphic traps. If the geophysicist feels, upon studying such data, that he may be able to delineate some few of the known traps, it would be well to allow him to try to do so, purely as an experiment. In fact, I believe that it would be quite worth the cost to conduct a few seismic surveys over a number of known stratigraphic traps in the hope that the opportunity of comparing the results obtained with the known conditions might enable similar conditions in the same areas to be recognized. Certainly, some experimental work of this sort should be done before concluding that the seismic method is not applicable.

It is fortunately no longer necessary to emphasize the importance of structures of low relief, but it still requires courage to drill them. In considering the validity of minor anomalies it is well to ask whether they are indicated by a pessimistic interpretation of the data. If so, they are real anomalies, and their significance must be considered, remembering that the significance of a structural anomaly is relative

to some preconceived standard. The insignificant anomaly, as judged by the standards of today, may well be judged a good prospect tomorrow. Even in spite of the general realization of this fact, I venture to state that many of the oil fields of tomorrow are already indicated on the better seismic maps of today as anomalies now considered too weak to test.

My personal specialty in the field of geophysics does not qualify me to suggest new provinces in which the seismic method may be used to advantage in the future. I am more concerned with those known provinces in which the method is relatively unsuccessful. These are of two main types, one in which the surface material is a high speed material, as for example the Cretaceous lime of the Edwards Plateau. The other is one in which accurate mapping is required on two or more closely adjacent beds, too close together to be resolved with the present technique. In the solution of these problems lies a great possibility for future progress. Although considerable experimental work has been done, much more should be done. The phenomena with which we deal are extremely complicated, and no one can say that even a more complete understanding of the properties of the earth will enable us to solve these problems. Nevertheless, I feel that more time and money should be spent on both research and experiments dealing with the fundamental properties of the earth and the propagation of waves therein, for in that approach lies the best chance of improving our technique.

Gravimetric surveys with the gravimeter will continue to be an important reconnaisance method, but it is not likely that the activity will continue long at its present level. The gravity meter permits of blanket coverage of extensive areas at moderate cost. If an original survey is properly conducted, the area need never be covered again.

It is probably too early to determine the value of the extensive, detailed surveys now being made. The great sensitivity of the gravimeter and the close spacing of stations customarily used results in the mapping of both major and minor anomalies, many of which are difficult of interpretation. The data now being obtained will be available for use in the future, when it is reasonable to expect that the physical significance of various types of observed anomalies will be better understood. In the meantime, the instrument will undoubtedly be used largely empirically, as a method of locating anomalies to be investigated by the seismic method. No further improvement in the gravimeter or in the technique of its use is needed. The difficulties encountered

are entirely in the interpretation. The instrument can and, I hope, will be used in locating piercement type domes undoubtedly existing off shore on the Gulf of Mexico. The day may yet come when a method will be found to develop oil fields so located.

I look for little change in the status of electrical methods of exploration. Future progress in their use can come only from a better understanding of their limitations and in the better recognition of areas suited to their use. The theoretical background of electrical prospecting is excellent, and the theory has repeatedly been checked by experimentation. In spite of this, few other methods have been more misused and an enormous number of ill-advised empirical tests of various systems have been made.

Electrical methods employing high frequency alternating current, or short electrode spacings, can delineate only surface or near surface features. In particular, the depth of penetration of currents of radio frequencies into earth materials of moderately low resistivities is extremely small. Systems employing direct or very low frequency alternating current may be used to map a bed at moderate depth in a few regions of simple geological structure. A suitable section is one in which a massive bed of high electrical resistivity is overlain by a fairly homogeneous material of lower resistivity. To work at depth, it is essential to use current electrode spacings some three to five times the depth of the layer to be mapped.

These well known principles are mentioned only to emphasize the necessity of the proper use of electrical methods. While they should continue to be considered as possible techniques, they should be used only in areas where information concerning surface features is known to be of diagnostic value, or in areas of extremely simple structures of a few particular types.

It has already been said that the unsolved problems in the field of seismic surveying require for their solution a more complete understanding of the properties of the earth strata with which we deal. The development of new methods of geophysical prospecting must similarly result from research work on fundamental problems. In fact, the development of a new method would seem to be dependent upon the recognition and evaluation of physical properties of the earth not delineated by any of the present methods. A new prospecting method is not likely to spring suddenly into being. The spectacular rise of the existing methods, sudden as it seemed, was based upon a substantial background of theoretical and experimental work in allied fields. The

possibility of utilizing the gravitational, magnetic, and acoustic properties of the earth in structural prospecting was recognized for many years before practical methods were evolved. The successful use of gravitational methods was made possible by the development of the Eotvos Torsion Balance. Similarly, the development of the seismic reflection method was made possible by the availability of the vacuum tube amplifier.

Most of the development and experimental work in the field of geophysical prospecting during the past fifteen years has been aimed toward improving instrumentation and field technique. This type of work has resulted in the development of the precision pendulum, the gravimeter, and in numerous developments in seismograph equipment. The cost of this work has been amply justified by the resulting reduction in prospecting costs and by the increased accuracy of the data obtained. The instrumentation and techniques of the existing methods have now reached a high state of perfection, but our understanding of many of the phenomena encountered in the practice of these methods is still lamentably imperfect. In the future, more time and money should be spent on research work on fundamental problems. Development programs promising immediate returns are superficially more attractive than broad research programs, the specific results of which are unpredictable, but only broad programs can result in major advances. The value of a research program is cumulative, and the economic value of any particular investigation may not be apparent for years after the work is done. As our background of fundamental knowledge increases, the necessity of subjecting suggested new methods to empirical tests will decrease. Empirical trials of new methods are tremendously expensive and time consuming. While a certain amount of empirical work will always be necessary, even a moderate reduction in the amount of such work can result in savings sufficiently great to pay for a large amount of basic research.

The development of a direct method of locating oil is an ever present hope but no proven method at present exists. Empirical trials of geochemical methods are now in process but no conclusive results are as yet available. The work being done with these methods illustrates very well the difficulties encountered when a theoretical or experimental background for a new method is lacking. While some of the reported results of these methods are encouraging, much more empirical work must be done before they can be accepted or rejected. In the meantime, work on the fundamental problems of the origin and man-

ner of accumulation of oil should continue to be actively pursued, since the solution of these problems is essential to the logical development of a method of locating oil directly.

Although the geological and geophysical staffs of the oil industry have the finding of oil as their primary function, both can be of assistance in problems connected with the drilling of wells and the production of oil. The aid given by the geologist is already extensive, that of the geophysicist will become increasingly important. The knowledge of earth properties gained by both field and laboratory work and many of the techniques developed in exploratory work can, and will be increasingly applied to problems outside that field. The electrical logging of bore holes is, to date, the outstanding example of the use of geophysical data in production problems. The recent introduction of radioactivity logs of bore holes is another contribution of the geophysicist. The sonic method now used to locate fluid levels in producing wells is an application of a technique used in seismic surveying. It is certain that other contributions will be made in the future by the technical staffs associated with the geophysical departments of the industry, and that the geophysics of the future will embrace a far wider field than it does at present.

It is to be hoped that the disturbed world conditions will not be allowed to interfere with the development of the geophysical arts as applied in the oil industry. While the harmful effects of a decrease in geophysical exploration or of serious interference with the normal progress of the art will not be immediately apparent, the long-term effects can not be viewed with equanimity. However dark the present may look, as individuals and professional men, we must never lose sight of the fact that our efforts of the present are of value only to the extent that they insure for us the future which we desire.

SEISMIC RECEPTORS*

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ABSTRACT

Development of equations of seismic receptor for both the steady state and dynamic case, illustrated by curves of steady state lag and steady state response for various degrees of damping, and also illustrated by graphs of response to transient impulses. A simple method of accurately obtaining the steady state displacement response and degree of damping is given.

INTRODUCTION

A knowledge of the theoretical characteristics of seismic receptors is useful both in the designing of apparatus and in the analyzing of seismograms. The theoretical steady state characteristics can be readily used in the construction and in the adjustment of the receptor. The theoretical dynamic response features are useful in the initial selection of the natural frequency and degree of damping and further useful in interpretation of receptor output.

EQUATIONS

The theoretical equations may be briefly developed as follows:

Let α be the motion of a receptor frame with reference to a point in space.

Let β be the motion of a receptor mass system with reference to a point in space.

Let θ be the motion of a receptor mass system with reference to its frame.

Then:

$$\beta = \alpha + \theta. \tag{1}$$

The equation of dynamic equilibrium is:

$$I \frac{d^2\beta}{dt^2} + k \frac{d\theta}{dt} + c\theta = 0. \tag{2}$$

Where I is the inertia of the receptor mass system including the inertia of any fluid in which the mass system is immersed and which is carried along by the motion of the mass system.

Where k is a damping constant.

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Where c is the force per unit displacement of θ.

For the first case let the motion impressed on the receptor frame be:

$$\alpha = A \cos (nt + \gamma) \tag{3}$$

$$\beta = \theta + A \cos (nt + \gamma) \tag{4}$$

$$\frac{d^2\beta}{dt^2} = \frac{d^2\theta}{dt^2} - n^2 A \cos (nt + \gamma) \tag{5}$$

$$\frac{d^2\theta}{dt^2} + \frac{k}{I} \cdot \frac{d\theta}{dt} + \frac{c}{I} \theta = n^2 A \cos (nt + \gamma). \tag{6}$$

Let $k/I = K$ and $c/I = N^2$.

Where $N = 2\pi F$ and $n = 2\pi f$.

Where F is the frequency of the receptor mass system, and f is the frequency of impressed motion.

The general equation becomes:

$$\theta = \theta_0 \epsilon^{-Kt/2} \cdot \cos \left[\sqrt{N^2 - \frac{K^2}{4}} \cdot t + \phi \right] \text{ (Transient Term)}$$

$$+ \sqrt{C_1^2 + C_2^2} \cdot A \cos \left[nt + \gamma - \arctan \frac{C_2}{C_1} \right]$$

(Steady State Term) (7)

Where:

$$C_1 = \frac{n^2(N^2 - n^2)}{(N^2 - n^2)^2 + K^2 n^2} \tag{8}$$

Where:

$$C_2 = \frac{Kn^3}{(N^2 - n^2)^2 + K^2 n^2} \cdot \tag{9}$$

The amplitude response in the steady state case is:

$$\sqrt{C_1^2 + C_2^2} \cdot A. \tag{10}$$

The phase angle in the steady state case is:

$$\arctan \frac{C_2}{C_1} \cdot \tag{11}$$

The phase time in the steady state case is:

$$\frac{\text{arc tan } \dfrac{C_2}{C_1}}{360 \cdot f}. \tag{12}$$

It is to be observed that the phase angle is with reference to the impressed motion. If the impressed frequency is quite large (n/N is great) the phase angle approaches 180 degrees and the mass acts as a pure inertia term. If the impressed frequency is quite small (n/N is small) the phase angle approaches 0 degrees and the mass acts as pure stiffness.

The electrical connections to a receptor may of course alter the apparent phase angle 180 degrees.

Figures 1, 2, 3, and 4 are curves of steady state characteristics computed from these formulae. It should be recognized that these curves apply to the displacement motion of the receptor mass system and not to the electrical output of the receptor.

In order to investigate the theoretical receptor response to wave trains the transient term of (7) must be considered in addition to the steady state term.

For this case when the time t is zero we have the following:

The impressed motion $\alpha = A \cos (nt+\gamma)$ (From (3))

When $t=0$, $\theta=0$, $\alpha=0$ and $\theta_0=\sqrt{C_1^2+C_2^2}\cdot A$

Therefore:

$$\gamma = 90^\circ \quad \text{and} \quad \alpha = A \cos \left(nt + \frac{\pi}{2} \right). \tag{13}$$

Substituting these values in (7) gives:

$$\epsilon^{-Kt/2} \cos \left[\sqrt{N^2 - \frac{K^2}{4}} \cdot t + \phi \right] = - \cos \left[nt - \text{arc tan } \frac{C_2}{C_1} + \frac{\pi}{2} \right] \tag{14}$$

$$\phi = - \text{arc tan } \frac{C_2}{C_1} + \frac{3\pi}{2} \tag{15}$$

$$\theta = \sqrt{C_1^2 + C_2^2} \cdot A \left[\epsilon^{-Kt/2} \cos \left(\sqrt{N^2 - \frac{K^2}{4}} \cdot t - \text{arc tan } \frac{C_2}{C_1} + \frac{3\pi}{2} \right) + \cos \left(nt - \text{arc tan } \frac{C_2}{C_1} + \frac{\pi}{2} \right) \right]. \tag{16}$$

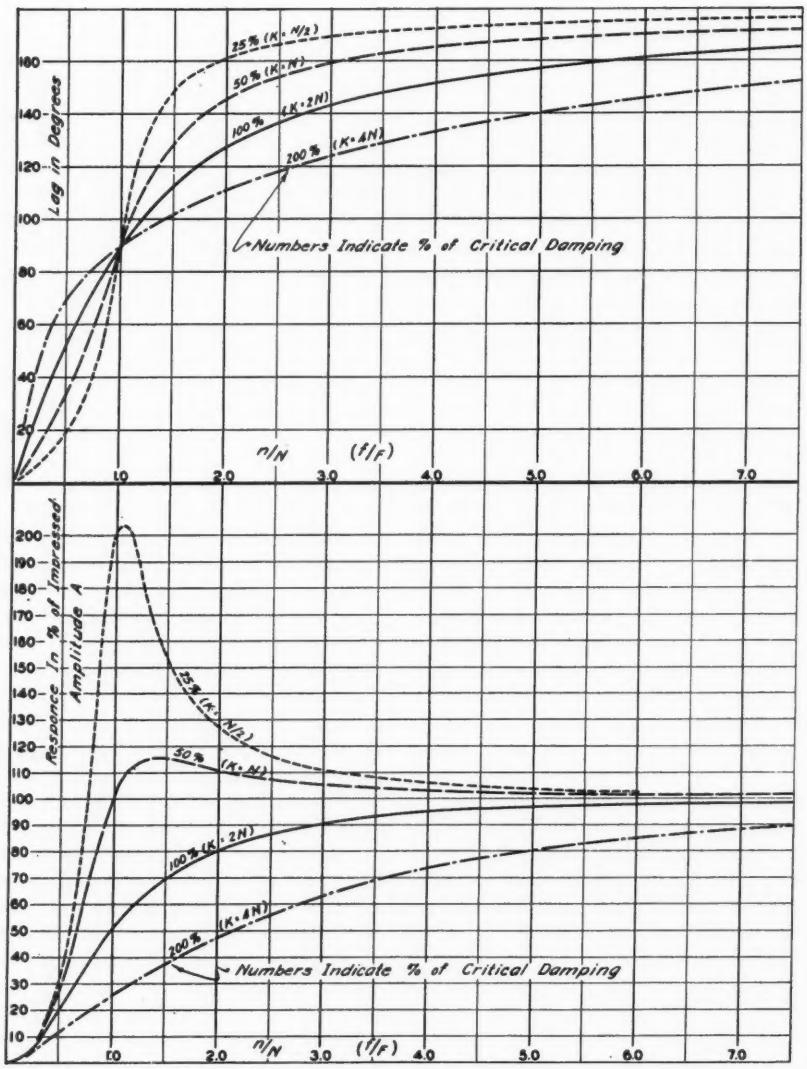

FIG. 1. Curves of steady state displacement response and displacement phase plotted against the ratio of impressed frequency to natural frequency for the moving mass system of a receptor having various degrees of damping.

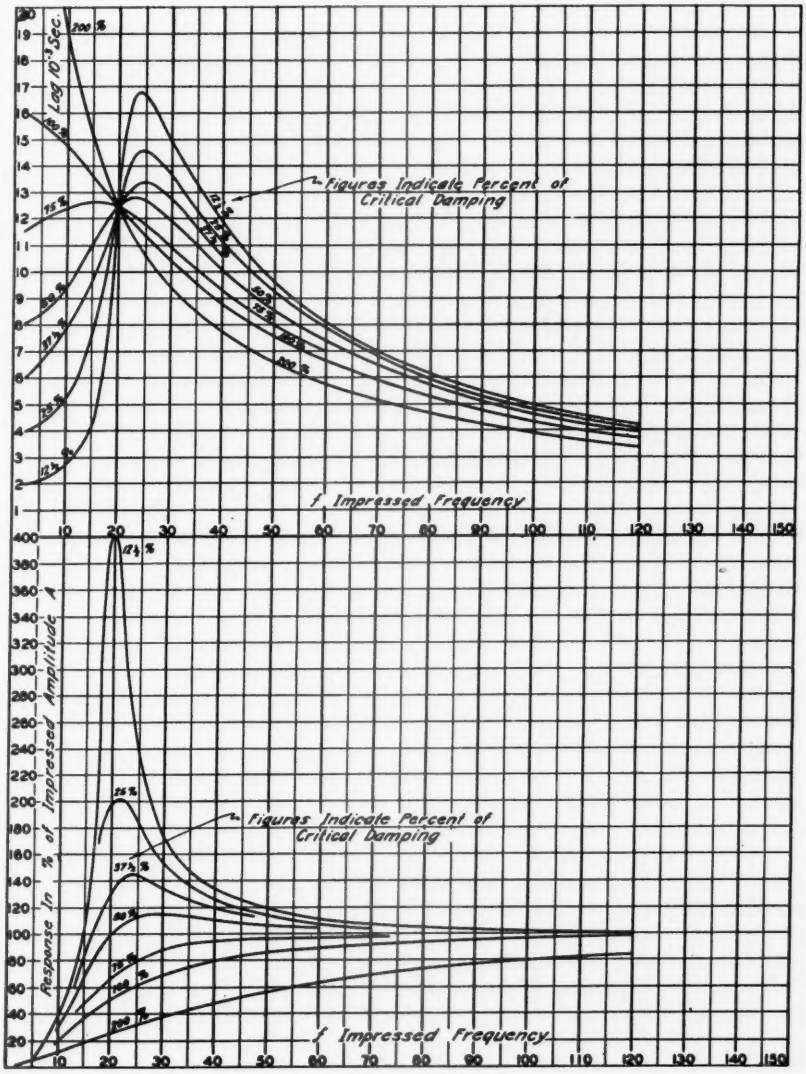
Lag 10^{-3} Sec.
Figures Indicate Percent of Critical Damping
f Impressed Frequency
Response in % of Impressed Amplitude A
Figures Indicate Percent of Critical Damping
f Impressed Frequency

FIG. 2. Curves of steady state displacement response and displacement lag plotted against the impressed frequency for the moving mass system of a receptor having a natural frequency of 20 cycles per second and various degrees of damping.

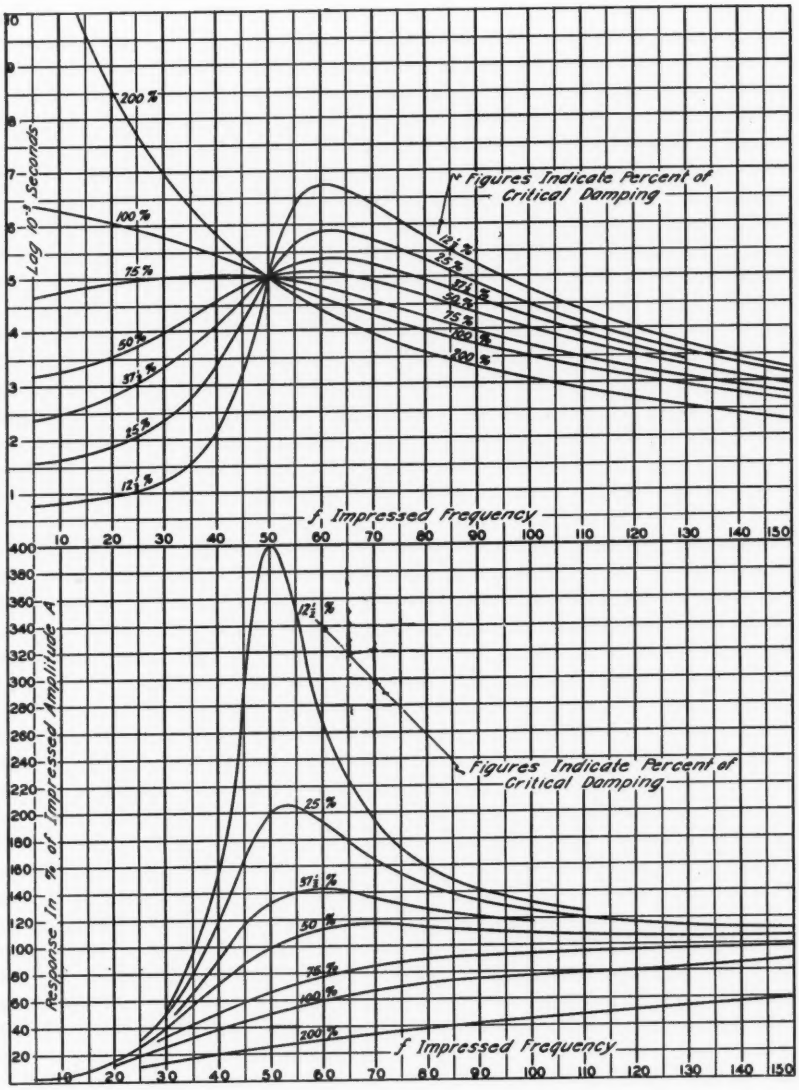

FIG. 3. Curves of steady state displacement response and displacement lag plotted against the impressed frequency for the moving mass system of a receptor having a natural frequency of 50 cycles per second and various degrees of damping.

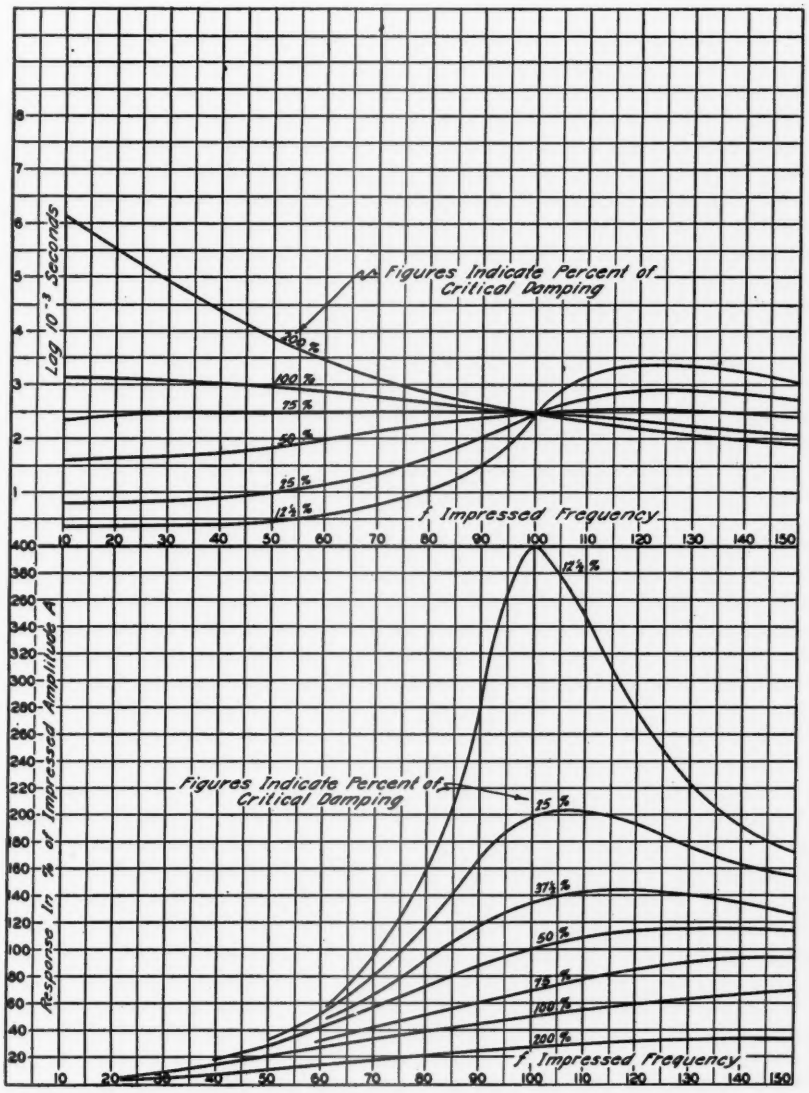

FIG. 4. Curves of steady state displacement response and displacement lag plotted against the impressed frequency for the moving mass system of a receptor having a natural frequency of 100 cycles per second and various degrees of damping.

This equation applies for the impact case leading finally after an interval of time to the steady state case.

All equations so far have been for single arrivals. If in addition to an arrival $A\cos(nt+\gamma)$ a second one occurs at a time t' $A'\cos(n't'+\epsilon)$ then:

$$\alpha = A\cos(nt+\gamma) + A'\cos(n't'+\epsilon) \tag{17}$$

$$\beta = \theta + A\cos(nt+\gamma) + A'\cos(n't'+\epsilon) \tag{18}$$

$$\frac{d^2\beta}{dt^2} = \frac{d^2\theta}{dt^2} - n^2A\cos(nt+\gamma) - n^{2\prime}A'\cos(n't'+\epsilon) \tag{19}$$

$$\frac{d^2\theta}{dt^2} + \frac{k}{I}\cdot\frac{d\theta}{dt} + \frac{c}{I}\theta = n^2A\cos(nt+\gamma) + n^{2\prime}A'\cos(n't'+\epsilon). \tag{20}$$

The solution is:

$$\theta = \sqrt{C_1^2+C_2^2}\cdot A\left[\epsilon^{-Kt/2}\cos\left(\sqrt{N^2-\frac{K^2}{4}}\cdot t+\phi\right) + \cos\left(nt+\gamma-\arctan\frac{C_2}{C_1}\right)\right] + \sqrt{C_1^{2\prime}+C_2^{2\prime}}\cdot A'\left[\epsilon^{-Kt'/2}\cos\left(\sqrt{N^2-\frac{K^2}{4}}\cdot t'+\phi'\right) + \cos\left(n't'+\epsilon-\arctan\frac{C_2'}{C_1'}\right)\right]. \tag{21}$$

By the same method as in (13), (14) and (15):

$$\phi = -\arctan\frac{C_2}{C_1}+\frac{3\pi}{2}, \qquad \phi' = -\arctan\frac{C_2'}{C_1'}+\frac{3\pi}{2} \tag{22}$$

$$\gamma = \frac{\pi}{2}, \qquad \epsilon = \frac{\pi}{2} \tag{23}$$

$$\theta = \sqrt{C_1^2+C_2^2}\cdot A\left[\epsilon^{-Kt/2}\cos\left(\sqrt{N^2-\frac{K^2}{4}}\cdot t-\arctan\frac{C_2}{C_1}+\frac{3\pi}{2}\right) + \cos\left(nt+\frac{\pi}{2}-\arctan\frac{C_2}{C_1}\right)\right]$$

$$+\sqrt{C_1'^2+C_2'^2}\cdot A'\left[\epsilon^{-Kt'/2}\cos\left(\sqrt{N^2-\frac{K^2}{4}}\cdot t'-\text{arc tan}\frac{C_2'}{C_1'}+\frac{3\pi}{2}\right)\right.$$
$$\left.+\cos\left(n't'+\frac{\pi}{2}-\text{arc tan}\frac{C_2'}{C_1'}\right)\right]. \qquad (24)$$

This equation applies for the two impacts leading finally after an interval of time to the steady state case.

When $A=A'$, $n=n'$, $C_1=C_1'$ and $C_2=C_2'$ the equation simplifies to:

$$\theta=\sqrt{C_1^2+C_2^2}\cdot A\left[\left[\epsilon^{-Kt/2}\cos\left(\sqrt{N^2-\frac{K^2}{4}}\cdot t-\text{arc tan}\frac{C_2}{C_1}+\frac{3\pi}{2}\right)\right.\right.$$
$$\left.+\cos\left(nt+\frac{\pi}{2}-\text{arc tan}\frac{C_2}{C_1}\right)\right]$$
$$+\left[\epsilon^{-Kt'/2}\cos\left(\sqrt{N^2-\frac{K^2}{4}}\cdot t'-\text{arc tan}\frac{C_2}{C_1}+\frac{3\pi}{2}\right)\right.$$
$$\left.\left.+\cos\left(nt'+\frac{\pi}{2}-\text{arc tan}\frac{C_2}{C_1}\right)\right]\right]. \qquad (25)$$

For one pulse motion of a sine wave the resulting receptor displacement may be obtained from equation (25) where the second arrival (t') starts one wave length later in time than the first arrival and 180 degrees out of phase.

It is to be observed in Fig. 5 that the apparent frequency of the onset displacement θ of the receptor is over twice that of the impressed motion α. Likewise the apparent frequency of the onset displacement in Fig. 7 is about three times that of the impressed motion. For electrical receptors where the output voltage is a derivative of the moving mass displacement the onset of the electrical output would therefore be increased relative to the following movement about twofold in Fig. 5 and would be increased about threefold in Fig. 7.

ELECTRICAL OUTPUT OF RECEPTOR

One of the most common types of seismic receptors uses the displacement θ to cut lines of magnetic flux in coils. Neglecting minor effects of phase changes caused by hysteresis, eddy currents, etc., the instantaneous induced electromotive force is proportional to the rate of cutting lines of flux.

$$e=-C'\frac{d\phi}{dt}\cdot \qquad (26)$$

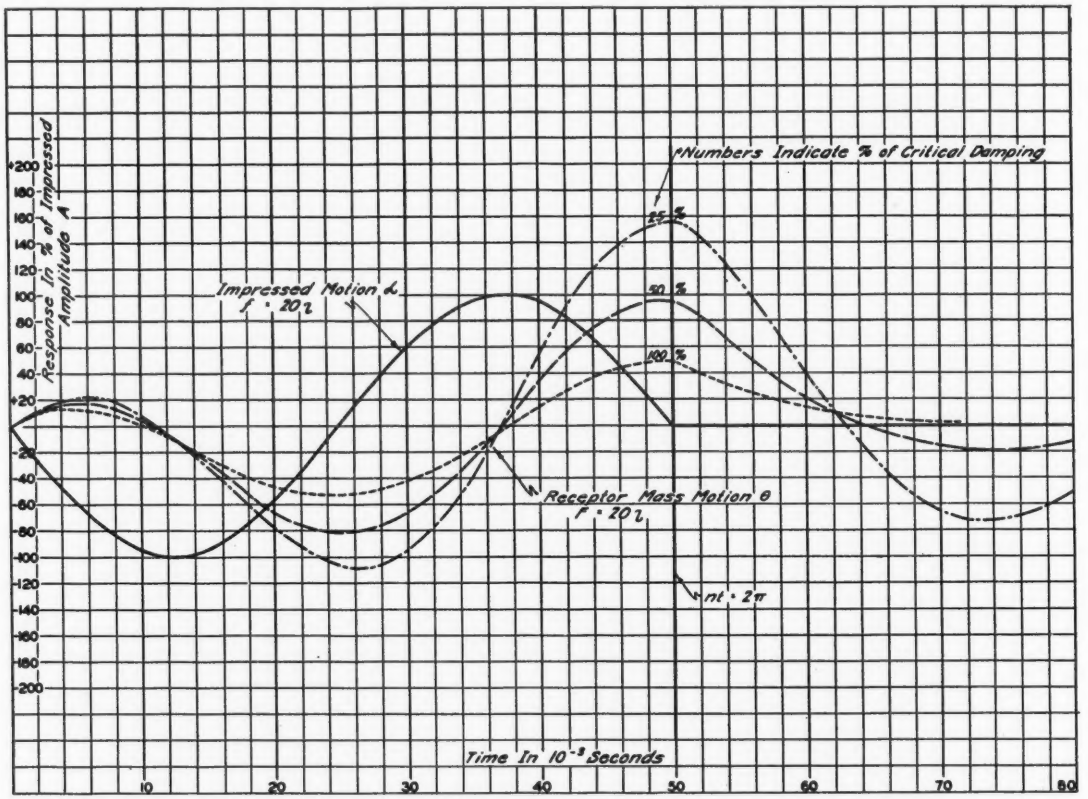

FIG. 5. Curves of dynamic displacement response plotted against time for a receptor having a natural frequency of 20 cycles per second and various degrees of damping, upon receiving an impressed motion of 20 cycles per second.

per second.

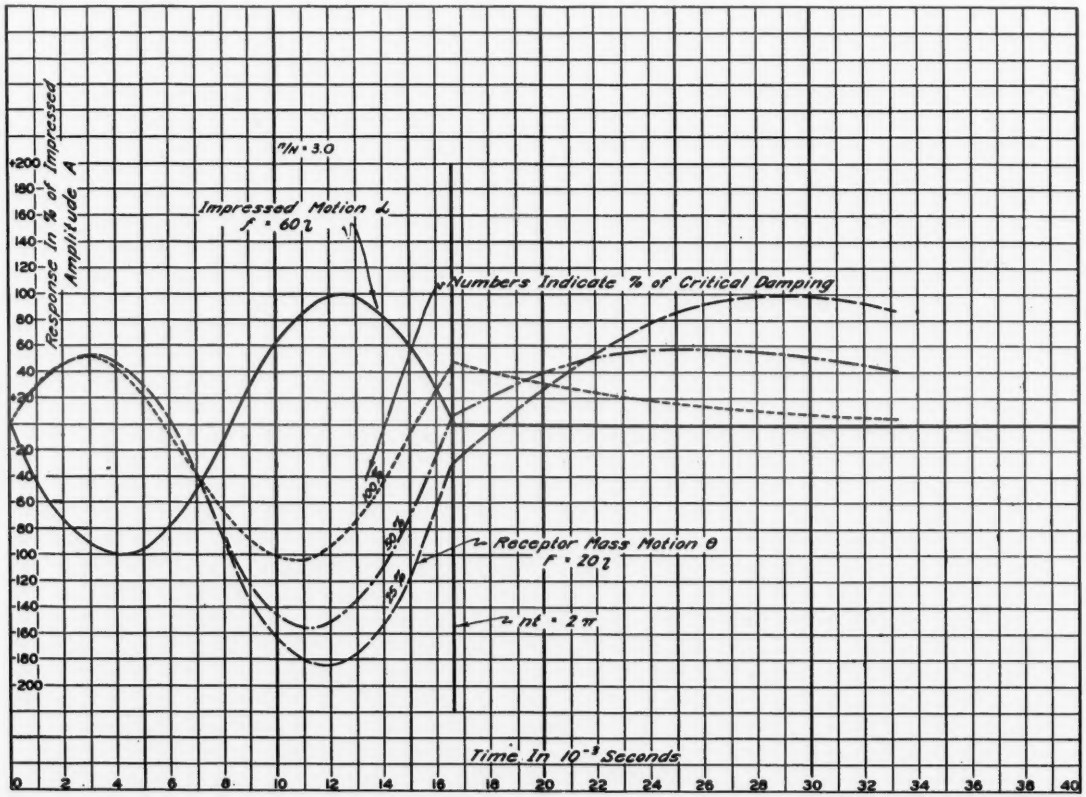

FIG. 6. Curves of dynamic displacement response plotted against time for a receptor having a natural frequency of 20 cycles per second and various degrees of damping, upon receiving an impressed motion of 60 cycles per second.

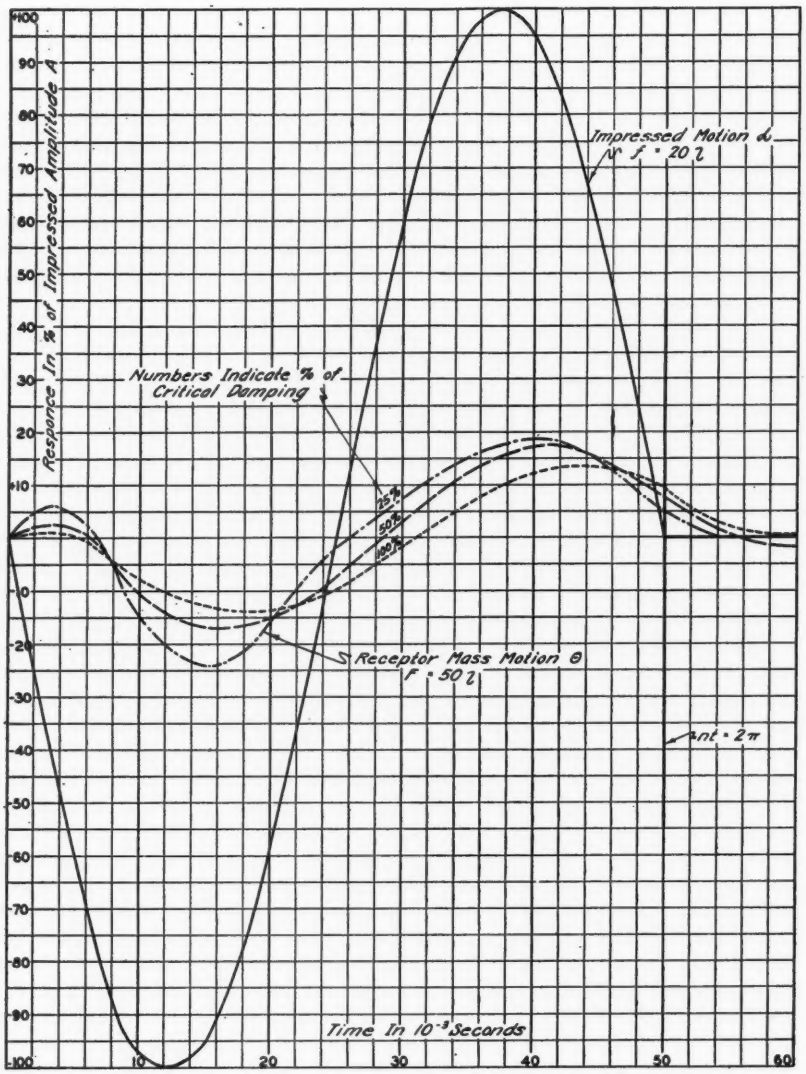

FIG. 7. Curves of dynamic displacement response plotted against time for a receptor having a natural frequency of 50 cycles per second and various degrees of damping, upon receiving an impressed motion of 20 cycles per second.

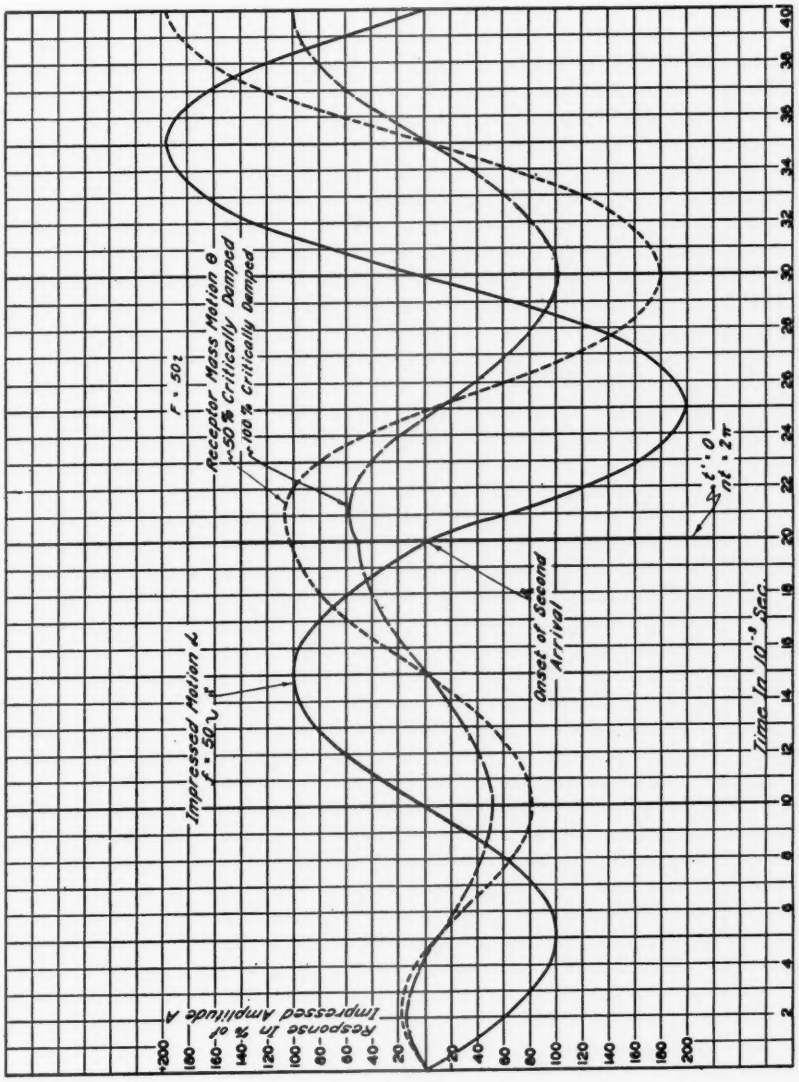
Response in % of Impressed Amplitude A
Impressed Motion ζ
f = 50 ν
Receptor Mass Motion θ
f = 50 % Critically Damped
f = 100 % Critically Damped
f = 50 ν
Onset of Second Arrival
Time in 10⁻³ Sec.
At t = 0
nt = 2π

FIG. 8. Curves of dynamic displacement response plotted against time for a receptor having a natural frequency of 50 cycles per second, upon receiving an impressed motion of 50 cycles per second followed by a second impressed motion of the same amplitude and frequency in phase with the first.

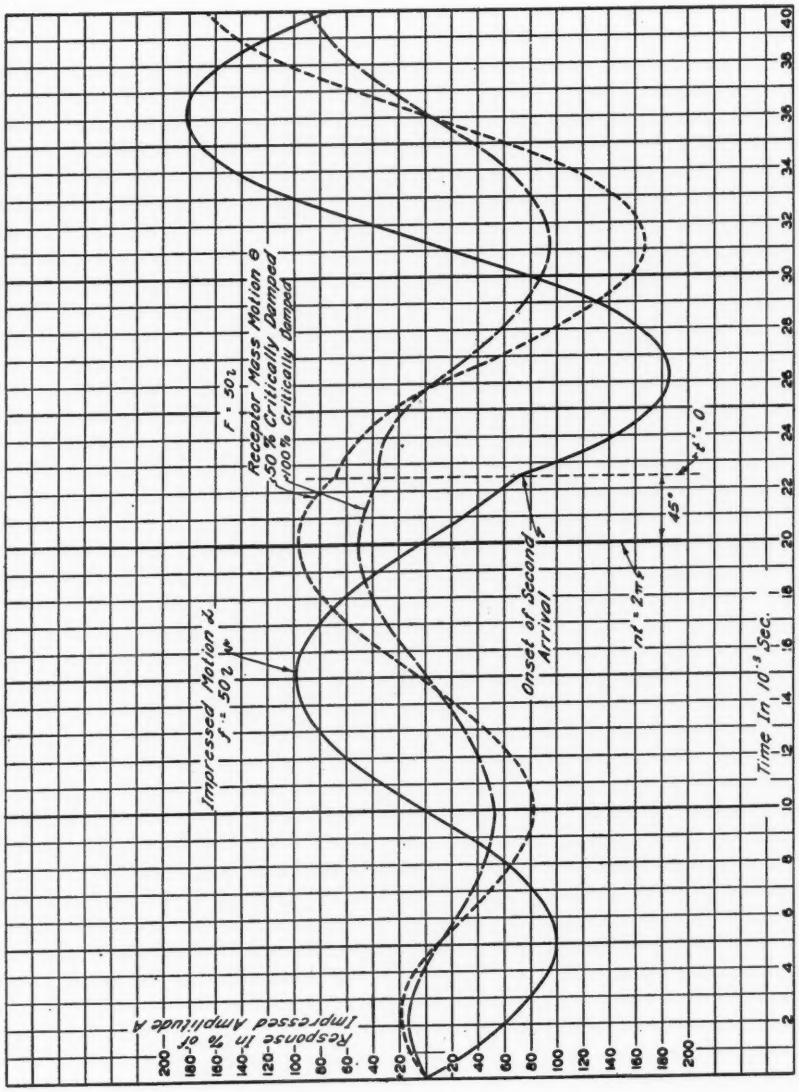

FIG. 9. Curves of dynamic displacement response plotted against time for a receptor having a natural frequency of 50 cycles per second, upon receiving an impressed motion of 50 cycles per second followed by a second impressed motion of the same amplitude and frequency 45 degrees out of phase with the first.

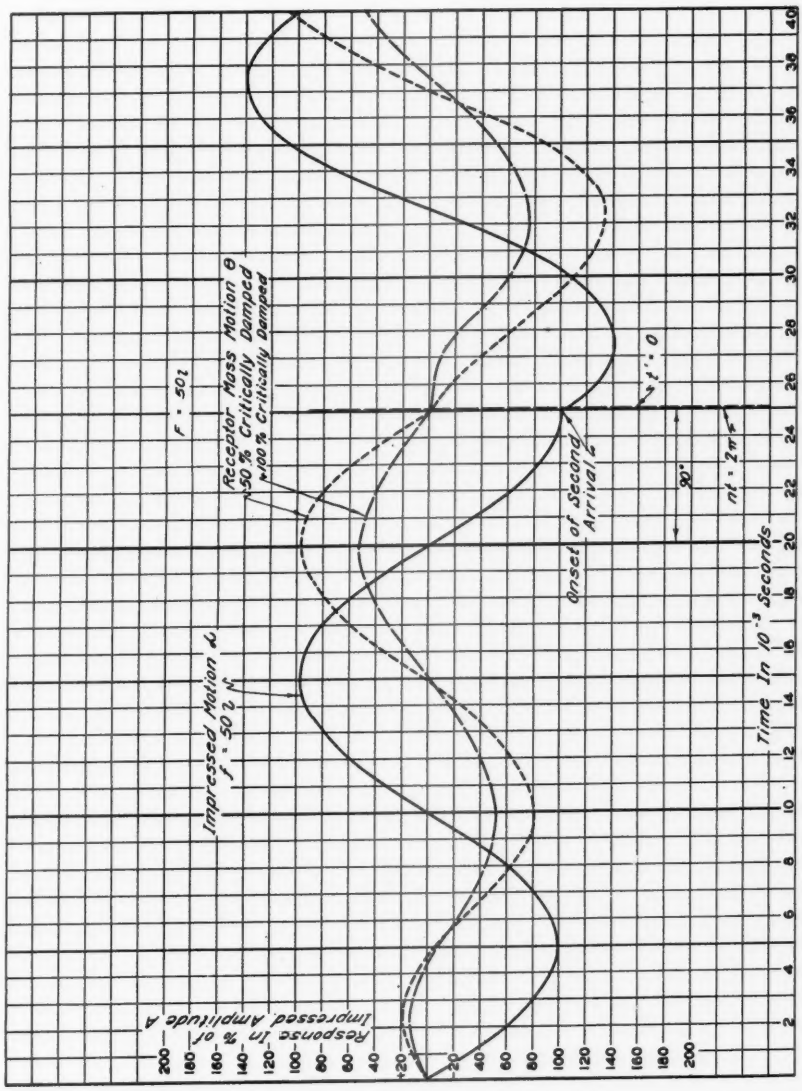

FIG. 10. Curves of dynamic displacement response plotted against time for a receptor having a natural frequency of 50 cycles per second, upon receiving an impressed motion of 50 cycles per second followed by a second impressed motion of the same amplitude and frequency 90 degrees out of phase with the first.

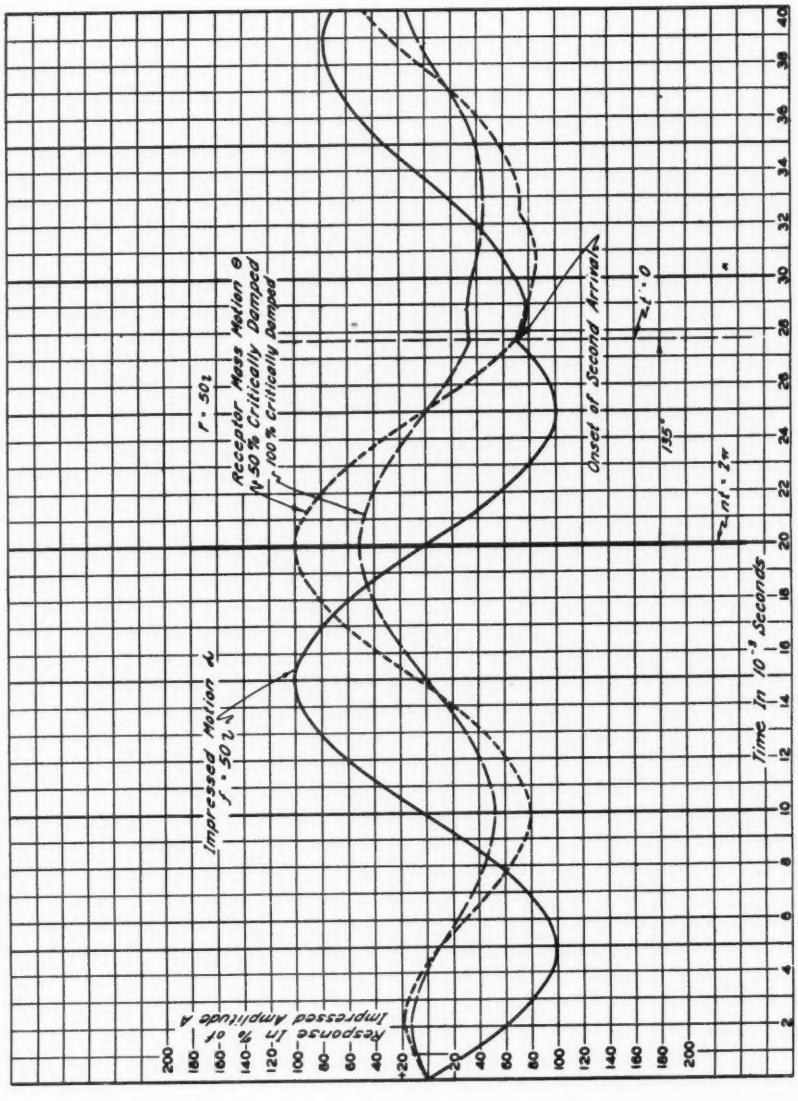

FIG. 11. Curves of dynamic displacement response plotted against time for a receptor having a natural frequency of 50 cycles per second, upon receiving an impressed motion of 50 cycles per second followed by a second impressed motion of the same amplitude and frequency 135 degrees out of phase with the first.

If the receptor mass motion $\theta = A \sin \omega t$ the voltage output becomes:

$$e = - k'A \cos \omega t = - E_{\max} \cos \omega t = - E_{\max} \sin (\omega t - 90^\circ). \quad (27)$$

Considering the steady state case the instantaneous induced voltage lags the motion θ by 90 degrees.

The polarity of the electrical output may of course be altered 180 degrees by reversing the connections whereby:

$$e' = + C' \frac{d\phi}{dt}. \quad (28)$$

This conventional polarity is illustrated by Fig. 12.

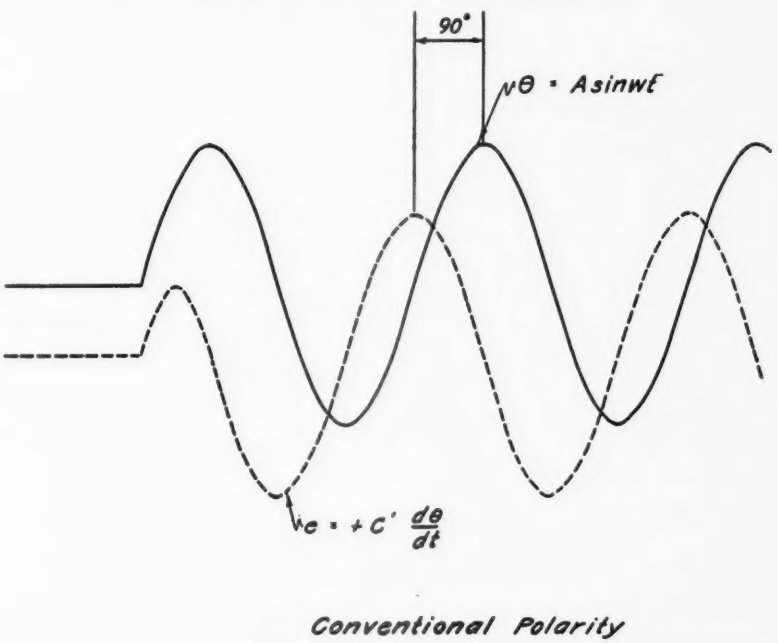

FIG. 12. Curves showing the relation between the displacement of the moving mass of the receptor and the electrical output.

It is interesting to note for the steady state case, using the polarity of Fig. 12, that if the impressed frequency is quite low (f/F is small), the receptor mass displacement θ is in phase with the impressed displacement α but the electrical output of the receptor has an apparent lead of 90 degrees. If the impressed frequency is quite high (f/F is

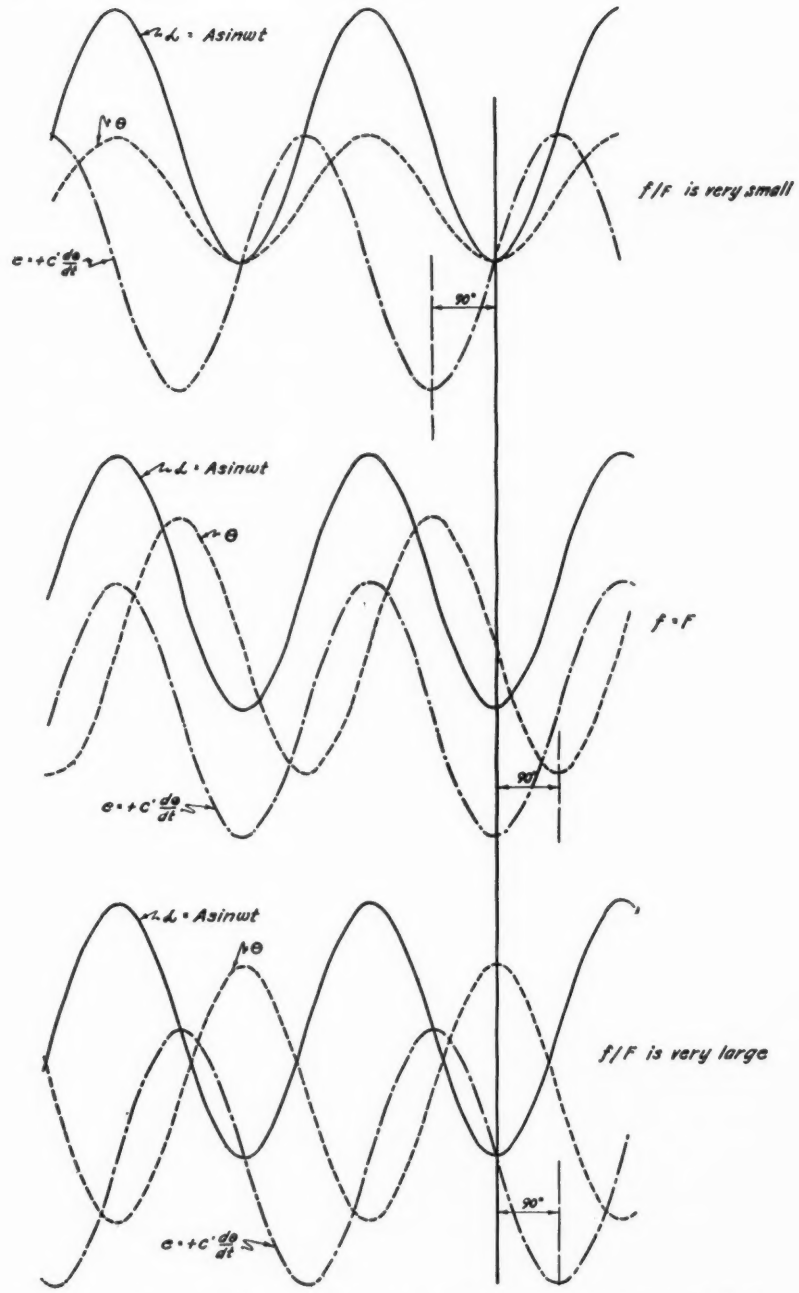

FIG. 13. Curves showing the steady state relation between the impressed displacement α, the receptor displacement θ and the electrical output e for the cases where (1) f/F is very small, (2) $f=F$ and (3) f/F is very large.

large), the receptor mass displacement θ lags the impressed displacement α 180 degrees but the electrical output of the receptor has an apparent lag of 90 degrees. When the impressed frequency is equal to the natural frequency of the receptor ($f=F$), the receptor moving system displacement θ lags the impressed displacement α 90 degrees but the electrical output of the receptor is in phase with the impressed movement. These three cases are illustrated by Fig. 13.

TESTING METHODS AND APPARATUS

Fig. 14 is a schematic layout of a shaking table useful for testing receptors. The actual displacement α which the shaker impresses on

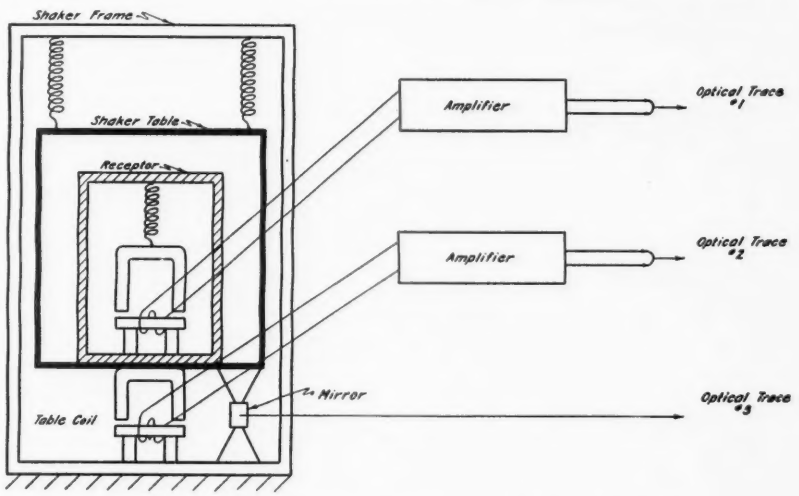

FIG. 14. A layout for a shaking table useful for testing purposes.

the receptor frame may be obtained by a mechanical linkage with a mirror. The linkage system must have a natural frequency much higher than that of motions impressed by the shaker on the receptor. The mirror may be used to place an optical trace directly on a record strip in common with the traces from the two amplifiers shown.

Between the shaker table and its support is positioned a magnetic and electric circuit, preferably identical to that positioned between the receptor frame and flexibly suspended mass system. Two identical amplifiers are used, one to connect to the receptor and the other to the table coil. This table coil should give a derivative of the motion given by the mirror, neglecting the lag of the amplifier.

The shaker table may be driven from a power amplifier. For investigation of steady state characteristics the input of the power amplifier may be connected to a beat frequency oscillator. For investigation of dynamic characteristics the input of the power amplifier may be connected to a transient generator.

Figs. 15 and 16 are the theoretical response traces for two cases using the shaking table layout of Fig. 14 and the polarity indicated in Fig. 12.

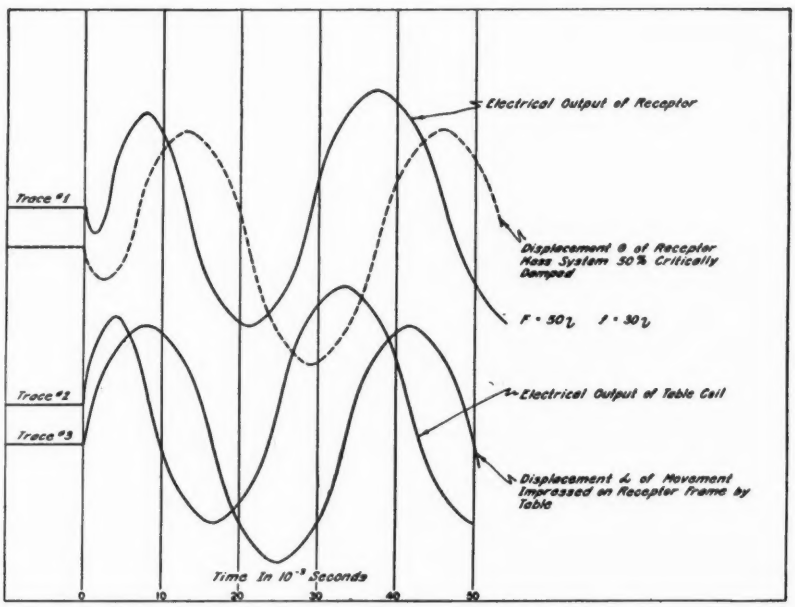

FIG. 15. Curves of dynamic response and phase relations for a receptor having a natural frequency of 50 cycles per second with one half critical damping upon receiving a 30 cycles per second impressed motion.

Figs. 17 and 18 are actual oscillograms taken by the system of Fig. 14 using a 40 cycle receptor one half critically damped. If allowance is made for a lag of about .002 seconds in the two amplifiers the actual oscillograms agree reasonably well with the theoretical response of Figs. 15 and 16.

Referring again to Fig. 14, the curve of steady state *displacement* θ of the receptor mass system may be obtained from step by step adjustment of the vibration of the table at various selected frequencies

so that the output of the table coils is constant and by plotting the output of the receptor coils. This will be more apparent if the case of a receptor having a very low natural frequency is considered so that the receptor mass system acts as pure inertia. If the output of the table coils is held constant as the frequency is changed then the electrical output of the receptor will also be constant because the pure inertia mass system would remain fixed in space so that the output of the receptor coils would be the same as that of the table coils. Should

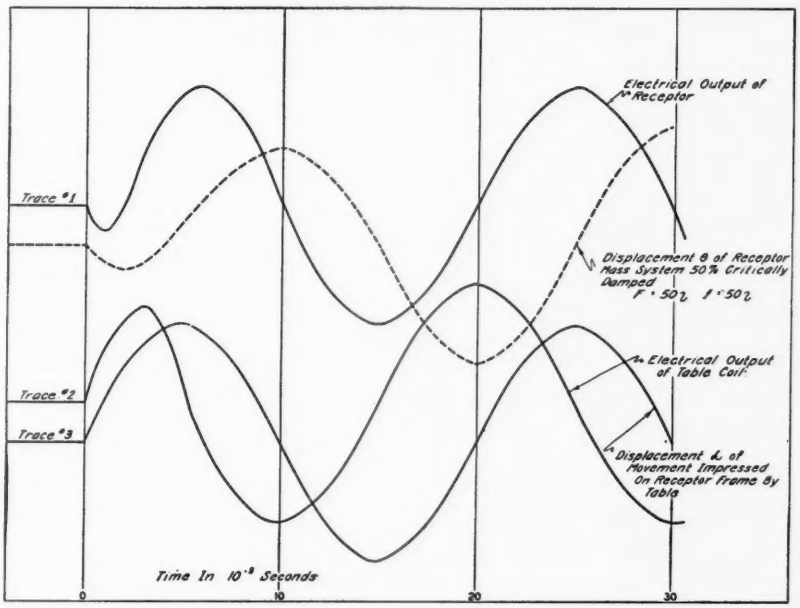

FIG. 16. Curves of dynamic response and phase relations for a receptor having a natural frequency of 50 cycles per second with one half critical damping upon receiving a 50 cycles per second impressed motion.

the receptor mass system move one-half as much as the table then the electrical output of the receptor would be one-half, etc. Therefore the displacement curve θ of the receptor moving system may be obtained by this simple method.

After the plot of the steady state displacement is available it may be superimposed on the theoretical response curves to determine the degree of damping and effective natural frequency.

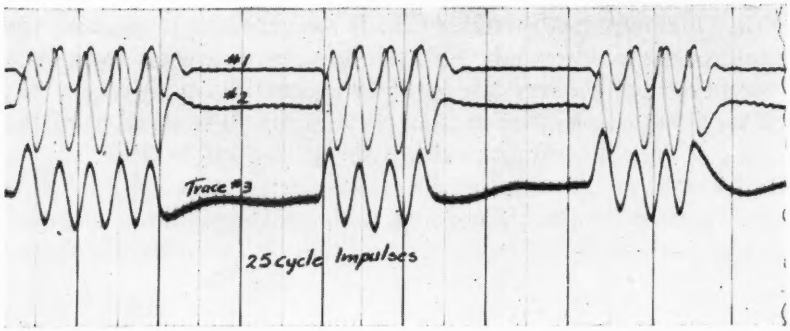

FIG. 17. Actual oscillogram of a receptor having a natural frequency of 40 cycles with one half critical damping where optical trace #1 is the electrical output of the receptor, where optical trace #2 is the electrical output of the table coils and where optical trace #3 is the displacement of the table using 25 cycle per second impulses

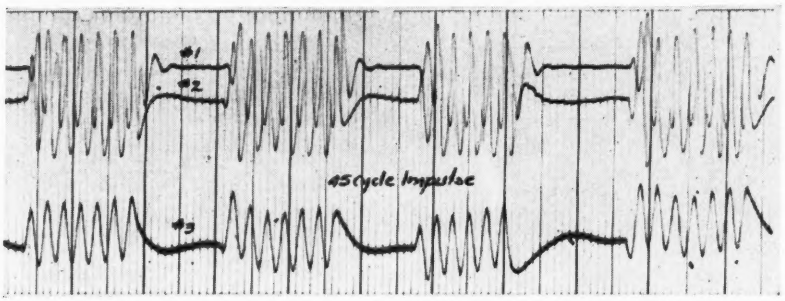

FIG. 18. Actual oscillogram of a receptor having a natural frequency of 40 cycles with one half critical damping where optical trace #1 is the electrical output of the receptor, where optical trace #2 is the electrical output of the table coils and where optical trace #3 is the displacement of the table using 45 cycle per second impulses.

Fig. 19 is a preferred scheme of plotting the theoretical steady state displacement curve θ where the maximum value of all curves is made the same. If a group of these for a variety of natural frequencies is available, and if the plot of the receptor displacement is made with the same maximum value on an overlay, the natural frequency and damping of the unit under test may be made very quickly.

For fluid immersed receptors it is useful to be able to determine the effective natural frequency after immersion because of the buoyancy and the tendency of the inertia to increase as a result of some of the fluid moving with the flexibly suspended moving system.

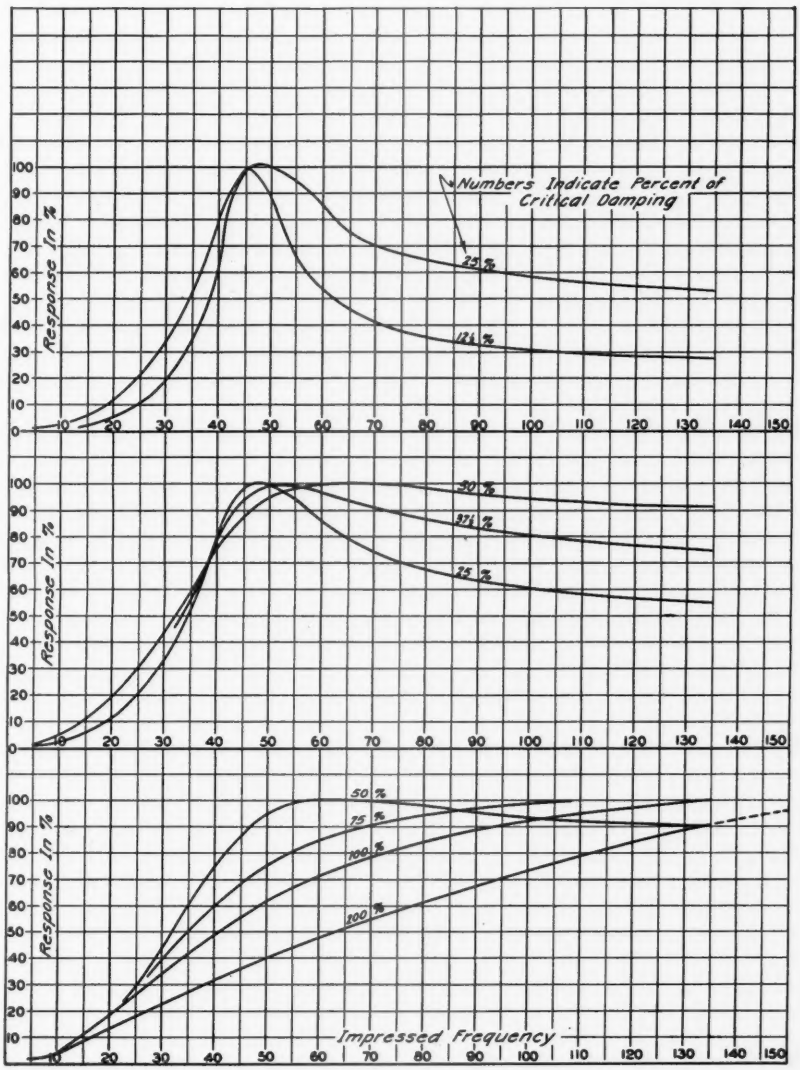

FIG. 19. Curves of steady state displacement response for a receptor having a natural frequency of 45 cycles and various degrees of damping where each curve is plotted in per cent of its own maximum.

Following the initial selection of receptor damping and natural frequency, a standard may be placed on the shaking table adjacent to the units under test. Comparison of response curves and of phase relations on a visual oscilloscope will serve as a double check on the adjustments necessary to make the test receptors substantially identical to the standard.

I wish to thank Continental Oil Company for permission to publish this material.

A REFRACTION THEORY ADAPTABLE TO SEISMIC WEATHERING PROBLEMS*

H. E. BANTA†

ABSTRACT

An exponential relation $V_y=C(y+A)^{1/n}$ between depth and velocity of propagation of seismic waves is postulated. The exponent is a number between zero and unity. Expressions for the time-distance relation, the depth-distance relation, the average vertical velocity, and the vertical time-horizontal time relation are derived. Applications of the relations to seismic weathering problems are discussed.

It would be difficult to postulate a seismic velocity-depth relation which could be applied to every area in which the seismograph is used. If an analytical expression is used for this relation, several arbitrary constants may be desirable. A quite flexible assumption is that

$$V_y = C(y + A)^{1/n}, \tag{1}$$

where y is depth and C, A, and n are constants for a given area. Then for two values of y, say $y=0$ and $y=h$, V may be determined:

$$V_0 = CA^{1/n}, \tag{2}$$

and

$$V_h = C(h + A)^{1/n} \tag{3}$$

where h is the depth at greatest penetration of a particular path.

The differential equation for any sound path in a medium where the velocity is a continuous increasing function of depth is

$$\frac{dy}{dx} = \sqrt{\left(\frac{V_h}{V_y}\right)^2 - 1}, \tag{4}$$

where x is the horizontal coordinate. Also,

$$\sin\theta = \frac{V_y}{V_h}, \tag{5}$$

where θ is the angle between the path and the vertical at depth y; and

$$\frac{dl}{dT} = V_h \tag{6}$$

* Presented at the Annual Meeting, Houston, Texas, April 1, 1941.

† Independent Exploration Company, Houston, Tex.

that is, the apparent surface velocity of propagation of the wave, given by the reciprocal of the slope of the time-distance curve, is the velocity of the wave at its point of maximum penetration. These relations are fundamental to any curved path theory.[1]

From (5),

$$\sin \theta_0 = \frac{V_0}{V_h} = \left(\frac{A}{h + A}\right)^{1/n}, \tag{7}$$

and

$$\sin \theta = \left(\frac{y + A}{h + A}\right)^{1/n}.$$

Hence

$$y = (h + A) \sin^n \theta - A,$$

and

$$dy = n(h + A) \sin^{n-1} \theta \cos \theta d\theta.$$

From (4)

$$\frac{dy}{dx} = \frac{\cos \theta}{\sin \theta},$$

hence

$$dx = n(h + A) \sin^n \theta d\theta,$$

and

$$\int_0^{l/2} dx = n(h + A) \int_{\theta_0}^{\pi/2} \sin^n \theta d\theta.$$

But

$$2n \int_{\theta_0}^{\pi/2} \sin^n \theta d\theta = 2n \int_0^{\pi/2} \sin^n \theta d\theta - 2n \int_0^{\theta_0} \sin^n \theta d\theta.$$

$$= f - Q.$$

[1] Ewing and Leet, A.I.M.M.E. Tech. Pub. #267, or M. M. Slotnick, "Seismic Computations", Parts 1 and 2, Geophysics, V. 1, No. 1, pg. 9, and V. 1, No. 3, pg. 299.

Then

$$h + A = \frac{l}{f - Q}. \tag{8}$$

The integrals appearing in (8), which are identified as f and Q, may be evaluated. It may be noticed that f is a definite integral, and a function of n only; whereas Q is a function of the constants A and n, and also h. From (8) the penetration, h, corresponding to any horizontal path length, l, may be calculated, provided that n and A can be determined.

In order to evaluate the constants it is necessary to calculate the travel time T in terms of l and the constants C, A, and n. Thus

$$T = 2\int_{0,0}^{l/2,h} \frac{ds}{V_y}$$

$$= 2\int_{0,0}^{l/2,h} \frac{\sqrt{\left(\frac{dx}{dy}\right)^2 + 1}}{V_y}\, dy.$$

As before,

$$T = \frac{2n(h + A)^{(n-1)/n}}{C}\int_{\theta_0}^{\pi/2} \sin^{n-2}\theta d\theta$$

$$= \frac{(h + A)^{(n-1)/n}}{C}[g - R], \tag{9}$$

where g is a definite integral and a function of n only; and R is a function of A, h, and n.

Eliminating h from (8) and (9),

$$l = \frac{f - Q}{(g - R)^{n/(n-1)}}(CT)^{n/(n-1)}, \tag{10}$$

a relation involving only l, T, and the constants C, A, and n.

In order to evaluate these constants, (10) may be written

$$\log T = \frac{n - 1}{n}\log l - \log K, \tag{11}$$

where

$$\log K = \frac{n - 1}{n}\log (f - Q) - \log (g - R) + \log C.$$

It can be seen that a set of time-distance data to which this theory is applicable should plot on a straight line on logarithmic coordinate paper. Furthermore, the slope of such a straight line is $(n-1)/n$, so that n may be determined.

Differentiation of (10) gives

$$\frac{dl}{dT} = \frac{n}{n-1}\frac{l}{T} = V_h. \tag{12}$$

Another quantity of interest is the time taken for a seismic wave to travel vertically to any depth. If T_v is this time, then

$$T_v = \int_0^h \frac{dy}{V_y} = \frac{1}{C}\int_0^h \frac{dy}{(y+A)^{1/n}}$$
$$= \frac{(h+A)^B - A^B}{CB},$$

where

$$B = \frac{n-1}{n}.$$

If $\overline{V}$ is the average vertical velocity, then

$$\overline{V} = h/T_v = \frac{CBh}{(h+A)^B - A^B}. \tag{13}$$

From this it is possible to show that

$$T_v + \frac{A^B}{BC} = \frac{T}{f-Q}. \tag{14}$$

In using any curved-path theory it is often not possible to assign a particular depth to the seismic weathered layer; instead, it is desirable to use some previously assigned depth which is great enough to include all low velocity material, and to calculate the vertical time to that depth for a seismic wave starting at the surface. The relation shown in (14) would enable this calculation to be made.

The integrals appearing in f and g may readily be evaluated for any value of n greater than unity, since they are a standard definite integral. No direct determination of A is immediately apparent; but, since

$$\theta_0 = \sin^{-1}\left(\frac{A}{h+A}\right)^{1/n}$$

Q and R may be calculated provided a relation between A and h is assumed. Fig. 1 shows $f-Q$ as a function of B for values of n between 2 and 10. Five values of the ratio A/h are used, from zero to 0.2.

A value of log K may be determined by substitution of experimental data in (11), provided the data plots on a straight line on logarithmic coordinate paper. If

$$S = \log C - \log K$$

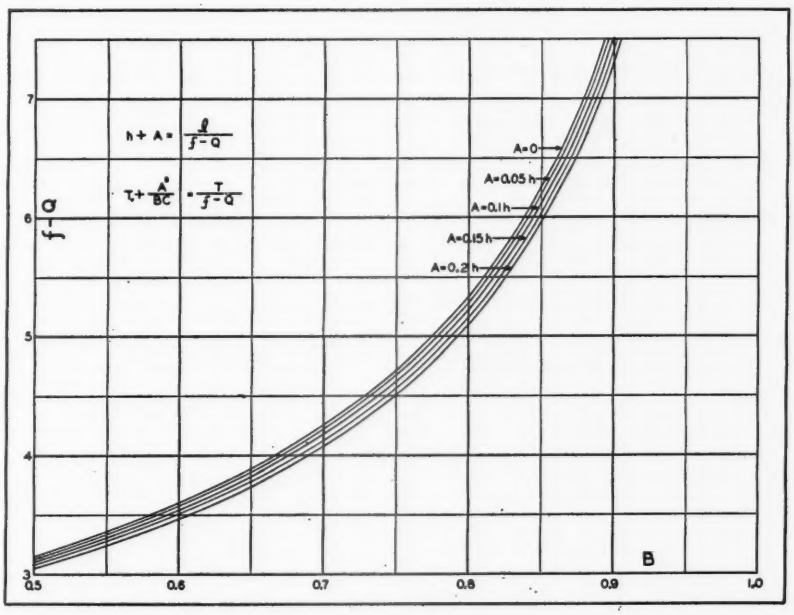

FIG. 1. The difference $f-Q$ as a function of B.

then S may be evaluated for certain values of n. Fig. 2 shows S as a function of B, for the same range as Fig. 1. It will be noted that a value for the constant A is to be determined by a process of successive approximations; the first assumption is that A is zero. A value for the constant C may then be calculated, and a value for A obtained from (2). The process may be repeated as many times as is desired.

Table I shows a representative set of time–distance data for a seismic weathering profile, and Fig. 3 shows a plot of these data on rectangular coordinates. Application of elementary theory to Fig. 3 gives 7 ft. as the thickness of the first layer, and 40 ft. as the thickness

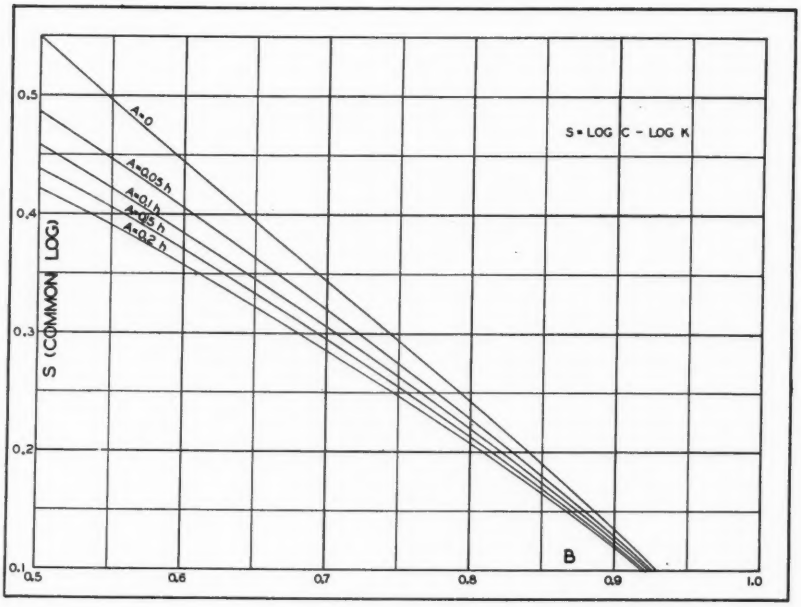

FIG. 2. S as a function of B.

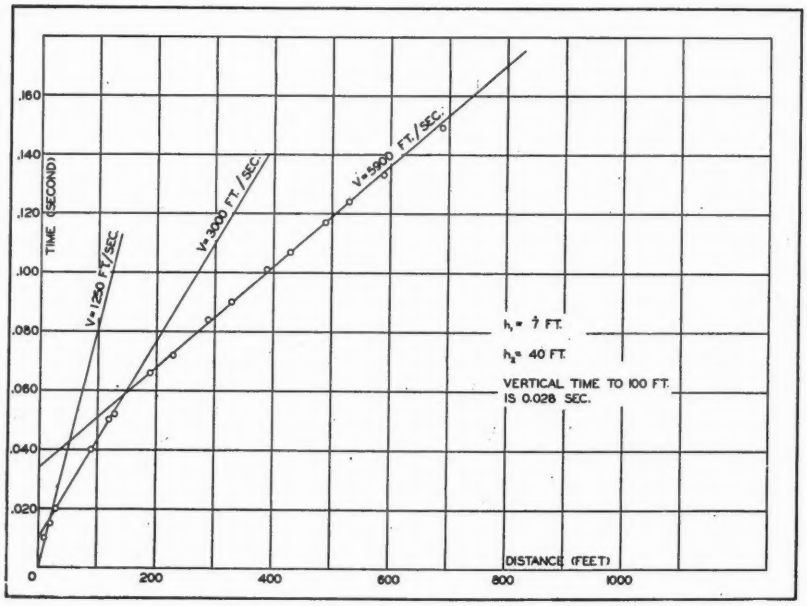

FIG. 3. A representative weathering profile. Coordinates are rectangular.

of the second layer. Thus the time for a seismic wave to penetrate vertically 100 ft. from the surface is 0.028 sec.

Fig. 4 shows the data of Table I plotted on logarithmic coordinate paper. Since B is 0.637, n is 2.75. Then, if A is zero,

$$f = 3.80, \quad \text{and}$$
$$S = 0.407.$$

Taking values from the line drawn through the plotted points, when l is 400 ft., T is 0.105 sec. Substituting these values in (11), log

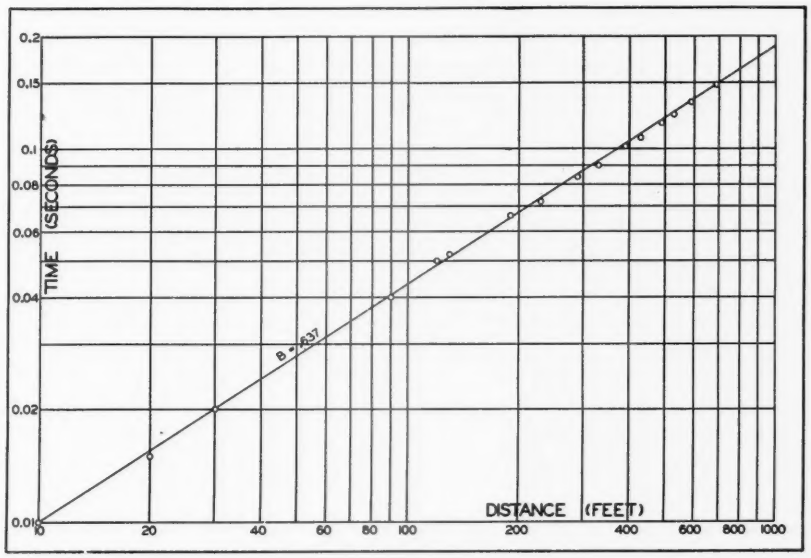

FIG. 4. The data of Table I and Fig. 3 plotted on logarithmic coordinate paper.

$K = 2.636$. Hence $C = 1104$. If the value of V_0 is taken as 1250 ft./sec., then from (2) $A = 1.407$ ft.

The second approximation may be started with the assumption that A is 0.014 h. Interpolating on the curves of Figs. 1 and 2,

$$f - Q = 3.78, \quad \text{and}$$
$$S = 0.398.$$

In the same manner as before, C is then 1082, and A is 1.487 ft.

Interpolating again,

$$f - Q = 3.78, \quad \text{and}$$
$$S = 0.397.$$

TABLE I

Distance (Feet)	*Time (Seconds)*
10	.010
20	.015
30	.020
90	.040
120	.050
130	.052
190	.066
230	.072
290	.084
330	.090
390	.101
430	.107
490	.117
530	.124
590	.133
690	.149

A representative set of time-distance data for a seismic weathering profile.

From (8), when h is 100 ft,

$$l_{100} = 384 \text{ ft.}$$

Then, from Fig. IV as before,

$$T_{100} = 0.102 \text{ sec.}$$

Substituting these values in (14),

$$T_V = 0.027 - 0.002 = 0.025 \text{ sec.}$$

This value may be compared with 0.028 obtained from Fig. 3 by use of elementary theory.

In many applications it would not be necessary to determine a value for A to a high degree of accuracy. Hence several steps indicated here might be omitted in some cases. It is even possible that in a good many cases equating A to zero would be good enough approximation.

In conclusion the author wishes to thank Mr. T. I. Harkins for permission to publish these calculations, and to Dr. F. M. Kannenstine for assistance in the preparation of this paper.

A NOTE ON THE DETERMINATION OF THE VISCOSITY OF SHALE FROM THE MEASUREMENT OF WAVELET BREADTH*

NORMAN RICKER†

ABSTRACT

From the breadth of a wavelet for a given travel time, it is possible to calculate the viscosity of the formation through which the seismic disturbance has passed. This calculation has been carried out for the Cretaceous Shale of Eastern Colorado, and the value thus found ranges from 2.7×10^7 to 4.9×10^7, with a mean value of 3.8×10^7 grams per cm. per second.

In a previous paper[1] the author presented a theory to account for the sinuous nature of seismograms. In this theory, supported by experimental evidence, it was demonstrated that the earth has an absorption spectrum for elastic waves, and that a sharp seismic pulse, as from an explosion, in being propagated through the earth is, by virtue of this absorption spectrum, to a large extent robbed of its high frequency components and thereby is converted into a traveling *wavelet*, of a characteristic, definite, and determinable shape, dependent upon the nature of the earth's absorption spectrum.

It further was developed that, in the case of such plastic formations as clays and shales, this absorption is of such a nature that the absorption coefficient is proportional to the square of the frequency. This, together with the observation that, in the range of frequencies generally encountered on our seismograms, there was no evidence of dispersion, showed that the absorption was in accord with that given by ordinary viscosity at low frequencies, as it affects waves of compression.[2]

In the case of plane periodic waves advancing along the positive x axis in shale, it was shown that the amplitude, A, of such waves could be expressed by

$$A = A_0 e^{-(f/f_0)^2 kx} \cos 2\pi f\left(t - \frac{x}{c}\right), \qquad (1)$$

* Presented at the Annual Meeting, Houston, Texas, April 1, 1941.

† The Carter Oil Co., Tulsa, Oklahoma.

[1] Geophysics, Vol. V, No. 4, Oct. 1940, pp. 348–366.

[2] G. G. Stokes, "Trans. Camb. Phil. Soc.," Vol. 8 (1845), pp. 287–319. Rayleigh, "Theory of Sound" Vol. II, pp. 315–316.

where A_0 is the amplitude at $x=0$, f is the frequency of the waves and c is the velocity of the waves (taken as a constant so long as the frequency, f, is low).

k and f_0 are constants (not independent) defined as follows: Setting k arbitrarily, then at a distance $x=1/k$, f_0 is that frequency at which the amplitude has decayed from A_0 to A_0e^{-1}. We can write $m=k/f_0^2$ as a constant of the medium.

The absorption spectrum of the earth at a distance $x=1/k$ is for shale as is shown in Fig. 1. In this figure is also shown the original shot pulse, the wavelet form into which this shot pulse is transformed in passing through the earth, as recorded by a mechanical seismograph, and the wavelet form as recorded by an electrical seismograph having a velocity type geophone and an amplifier with uniform response to all frequencies.

The wavelet form as recorded by a mechanical seismograph is represented by the function

$$\frac{\sqrt{\pi}}{2}\cdot\frac{u}{2}e^{-u^2/4}. \tag{2}$$

Similarly the wavelet form as recorded by an electrical seismograph is represented by the function

$$\frac{\sqrt{\pi}}{2}\left(\frac{u^2}{4}-\frac{1}{2}\right)e^{-u^2/4}, \tag{3}$$

where the argument u is given by

$$u = 2\pi\frac{f_0}{k^{1/2}}\cdot\frac{\dfrac{x}{c}-t}{x^{1/2}}. \tag{4}$$

Let T be the travel time of the wavelet center. Then

$$u = 2\pi\frac{f_0}{k^{1/2}c^{1/2}}\cdot\frac{T-t}{T^{1/2}}, \tag{5}$$

t being the time to any part of the wavelet under consideration. Calling $T-t=\Delta t$ we see that Δt is the time interval from the wavelet center to any part of the wavelet. Let the breadth of the wavelet between maxima, in seconds, be b. Then $b/2$ is the time interval between the wavelet center and either maximum of the wavelet. Now the wavelet form

$$\frac{\sqrt{\pi}}{2}\left(\frac{u^2}{4}-\frac{1}{2}\right)e^{-u^2/4} \tag{6}$$

reaches a maximum for $u=\pm\sqrt{6}$. So writing $u=\sqrt{6}$ and $\Delta t=b/2$ we have

$$\sqrt{6} = 2\pi \frac{f_0}{k^{1/2}c^{1/2}}\cdot\frac{b/2}{T^{1/2}},$$

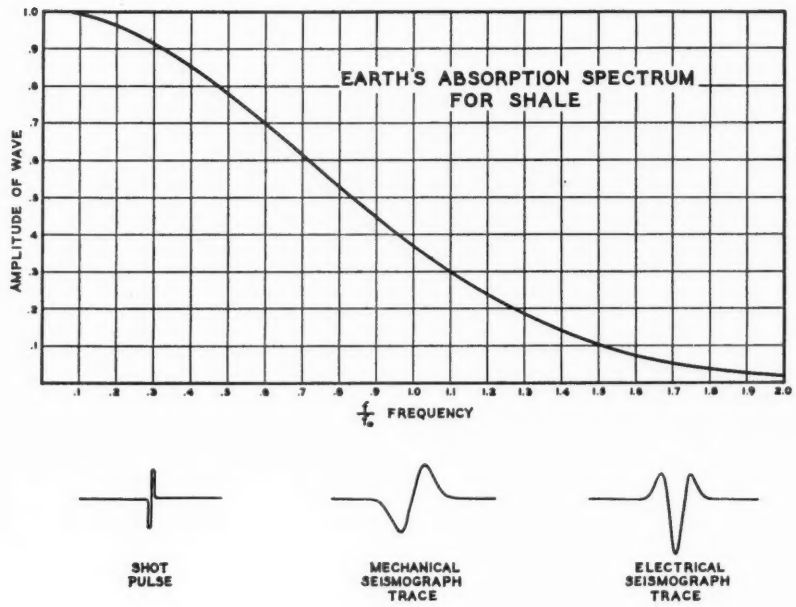

FIG. 1

or

$$6 = \frac{\pi^2 f_0^2}{kc}\cdot\frac{b^2}{T}\cdot \tag{7}$$

Now, according to Stokes' formula for the absorption coefficient, α, of periodic compressional waves of frequency, f, in a medium of viscosity, η

$$\alpha = \frac{8\pi^2\eta}{3\rho c^3}f^2$$

as compared with our expression for α

$$\alpha = \frac{k}{{f_0}^2} f^2.$$

So that

$$\frac{k}{{f_0}^2} = \frac{8\pi^2\eta}{3\rho c^3}.$$

We have then

$$\eta = \frac{\rho c^2}{16} \cdot \frac{b^2}{T}. \tag{8}$$

Now b^2/T is a constant of the medium and may be determined by measurements of wavelet breadth for various travel times.

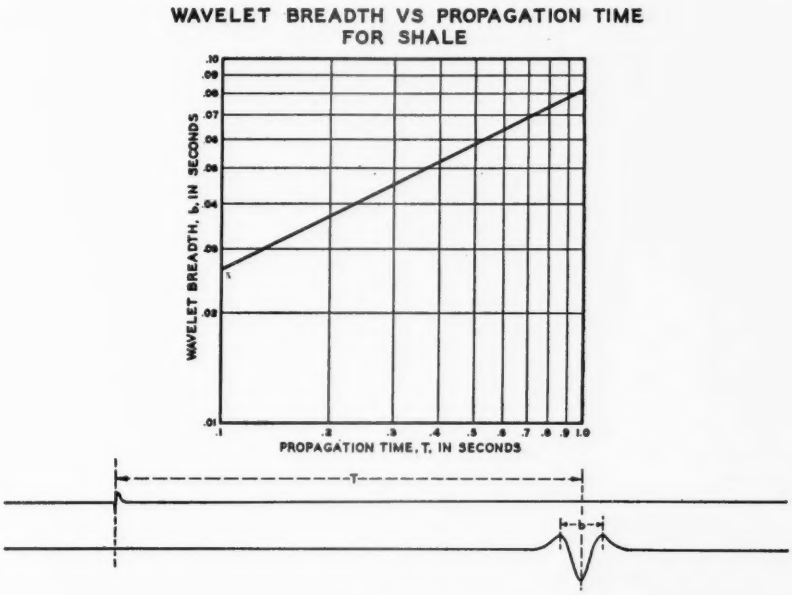

FIG. 2

Thus it is a property of these wavelets to broaden with increasing travel time so that the breadth, b, of such a wavelet is proportional to the square root of the travel time, T, and from the ratio b^2/T together with the density, ρ, of the medium and the velocity, c, of compressional waves in the medium, the viscosity, η, may be determined.

In Fig. 2 is shown the relation between the breadth of the wavelet

and the travel time as determined experimentally for the Pierre Shale of Eastern Colorado. This shale is of Cretaceous age and is several thousand feet thick in the area where the studies were made. In order to obtain a representative value for the viscosity of this shale, two extreme values have been calculated, one from near surface studies, and one from deep studies.

Since the determination of the viscosity requires a knowledge of the density of the shale and the velocity of the compressional waves through it, as well as the ratio b^2/T, our precision can be no better than the precision to which the least measurable of these quantities is known. This probably is the density.

For the near surface density a value of 2 grams per cc. has been used. The velocity of the primary compressional wavelet was determined with fair precision and found to be 5850 feet per second or 1.78×10^5 cms. per sec. The ratio b^2/T was found to be .0067 secs. So we arrive at a value for the near surface viscosity

$$\eta = 2.7 \times 10^7 \text{ gms. per cm. per sec.}$$

The value of the viscosity at depth is probably some better. With the density taken as 2.3 grams per cc. and the measured velocity of 7,300 ft. per sec. or 2.23×10^5 cm. per sec., as obtained at depth with refraction spreads 8,000 to 9,000 feet from the shot point, we obtain a value of

$$\eta = 4.9 \times 10^7 \text{ gms. per cm. per sec.}$$

The mean of these extreme values is

$$\eta = 3.8 \times 10^7 \text{ gms. per cm. per sec.}$$

DEEP CORRELATION REFLECTIONS NEAR HOSKINS MOUND SALT DOME*

F. F. CAMPBELL†

ABSTRACT

Seismograph records shot north of Hoskins Mound Salt Dome are presented which show correlatable reflections beyond four seconds. Faulting and a major unconformity are suggested to explain the observed data.

During the course of a deep reflection program in August, 1935, in the vicinity of Hoskins Mound salt dome in Brazoria County, Texas, a line of profiles was laid out north from the dome as shown in Fig. 1. The outline of cap rock or salt at minus 2,000 feet, shown as a heavy dashed line, was taken from a paper by Archer.[1] The zero stake on the line of profiles is about a half mile north of this outline and stations on the line are measured north from it in hundreds of feet.

It was anticipated that reflections from steeply dipping beds against the flank of the dome might be obtained on profiles shot as far as a mile north of the dome, so charges were loaded to give energy to a time of 3.5 seconds. The profile shot north from station 40, which is a little more than a mile from the dome, showed an indication of a reflection at 4.4 seconds, although a charge of only six pounds of gelatin dynamite was used; the charge being loaded in a hole 24 feet deep. Increasing the charge to thirty pounds brought out this reflection so well that the possibility of correlating it was suggested. The records presented in Fig. 2 were shot for this deep reflection at stations still further away from the dome.

Portions of four records[2] are shown in Fig. 2. In the reproduction, a portion of each record is omitted, the gap corresponding approximately to the time interval of 0.5 to 3.8 seconds. This arrangement emphasizes the positions of the geophones in regard to the deep reflection. Automatic amplitude control was not employed in the recording channels, so the records show the true relative amplitude of the reflections. The level of ground unrest is barely appreciable ahead of the

* Presented at the Annual Meeting, Houston, Texas, April 1, 1941.

† Geophysical Research Corporation, Tulsa, Oklahoma.

[1] M. Marx Archer, "Hoskins Mound Salt Dome, Brazoria County, Texas." Bulletin A.A.P.G. Vol. 20, No. 2, Feb. 1936, pp. 155–78.

[2] The galvanometer lines in the later parts of the records were darkened with a heavy pencil before reproduction.

first breaks. The two records, marked "*A*",-at the top of the Figure, were shot south from station 160 at the distances shown at the left-hand side of the records, and the two records, marked "B," at the bottom of the Figure were shot south from station 70 at the distances indicated. The shot points "A" and "B" are indicated on Fig. 1.

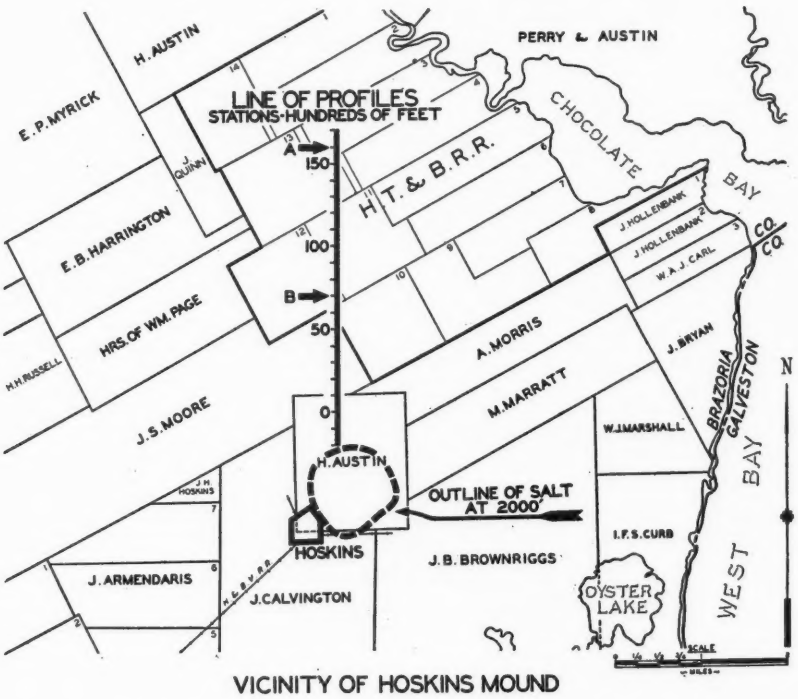

FIG. 1. Vicinity of Hoskins Mound Salt Dome, Brazoria County, Texas, showing outline of salt or cap rock material at minus 2000 feet and location of line of profiles.

The deep reflection on the "A" records arrives at 4.1 seconds compared to 4.4 seconds on the "B" records. This time difference of 0.3 seconds corresponds to enormous relief in less than two miles, and makes immediate correlation doubtful. There are also some character changes across the records which detract from the correlatability of the reflections. On the "A" records the trough preceding the major one varies in amplitude, and on the "B" records the energy band is wider on the top traces than on the bottom traces. Yet in spite of these character variations and the large time difference, the outstanding nature

of the arrivals favors direct correlation. The dips of the reflections add important evidence to the interpretation. For it may be noted that the reflection times on the "B" records have a normal pattern with regard to the first breaks and indicate 1.5 degrees of north dip, while the pattern of the reflection times on the "A" records is decidedly abnormal. The longest trace, which is at the top, has the shortest time instead of the longest time which would be expected normally, and the pattern of the reflection times is concave to the left compared to the normal pattern which is concave to the right. The upper "A"

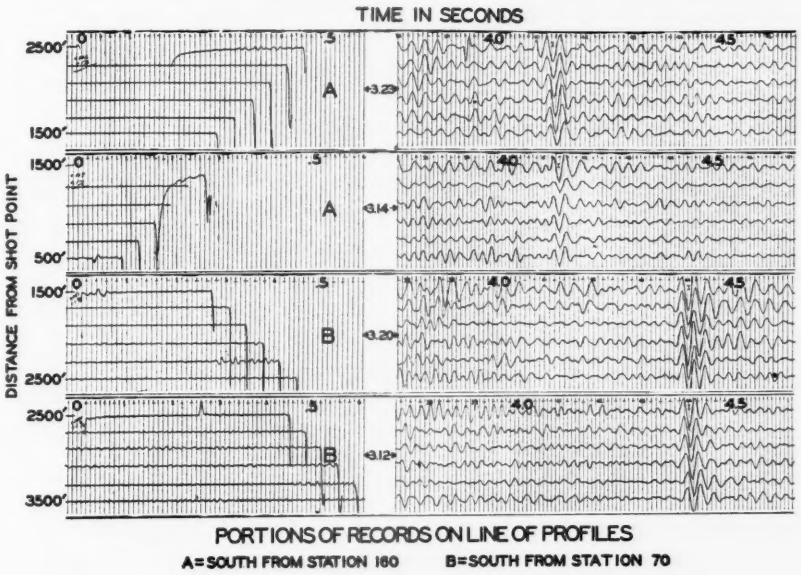

FIG. 2. Portions of four records from line of profiles.

record shows 8.5 degrees of north dip and the lower one 2.5 degrees of north dip. The inclination and relative positions of these reflections may be studied on Fig. 3 which is a vertical cross-section of the whole line of profiles.

In Fig. 3 the horizontal and vertical scales are indicated at the top and sides of the Figure and they are the same. For clarity in reproduction the cross-section begins at a depth of minus 3,000 feet. The positions of the reflection segments were determined by geometrical construction assuming a straight line path. A velocity of 6,550 feet per second was used to plot the shallowest reflections shown. The

velocity used was increased, as the depth of the reflections increased, to a maximum of 7,500 feet per second at a depth of 9,000 feet. For reflections below this depth a constant velocity of 7,500 feet per second was used. Since this velocity is probably too low, the plotted positions of the deeper segments are probably too shallow, although they

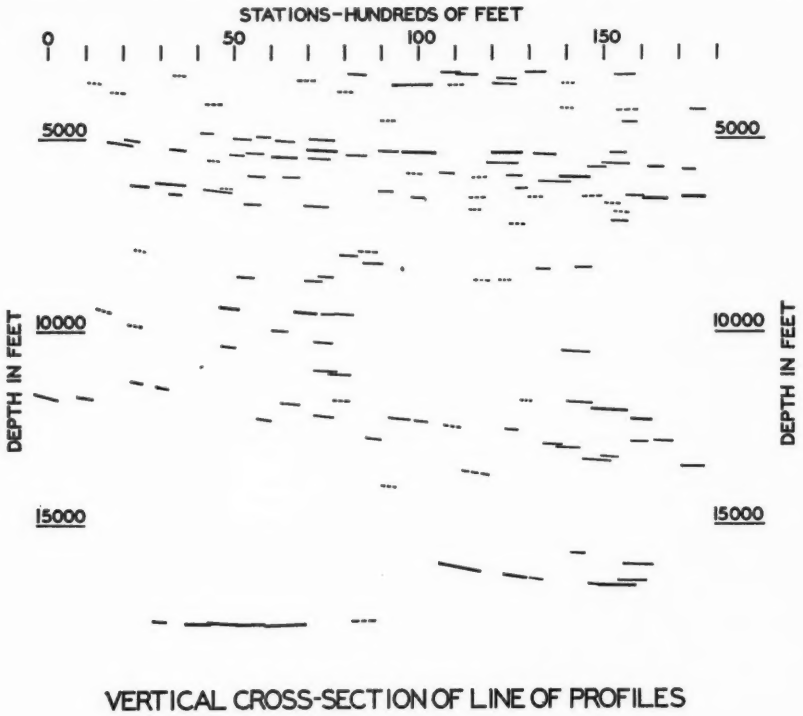

FIG. 3. Vertical cross-section of line of profiles.

are relatively correct. The shading of the line segments is proportional to the grade of the reflection: heavy—good, light—fair, dashed—poor.

The "B" records are typical of those obtained at the south end of the line. There is a correlated horizon shown at a depth of 17,600 feet with very little relief along it. There are steeply dipping beds higher in the section whose positions are determined by shallower reflections on records shot with lighter charges than those used for the records in Fig. 2. There is a gap in the deep correlated horizon beginning at station 90 and extending to station 105. North of this station there is

a correlated horizon at a depth of 16,000 feet which is dipping steeply to the north. At station 150 it is at a depth of 16,600 feet, but the rate of dip has decreased nearly to zero. The "A" records are critical ones on the north part of the line, for the upper one determines the position of the correlated horizon at station 110 and the lower one at station 140. Shallower reflections show a gradual decrease in the rate of dip as one proceeds up the section.

The correlation of the deep horizons across the gap in the middle of the line is not certain, but a tension fault could account for the displacement of the reflecting horizon as well as the unusual tilting on either side of it. It is also clear that a major unconformity exists above 16,000 feet and probably below 14,000 feet.

The following hypothesis may explain the development of the indicated structure: In the early stages of the upward movement of the salt into what became the Hoskins Mound dome, the movement covered a large area but was confined vertically by a competent section. Within this section was the formation which is now responsible for the correlatable reflection. As the salt flowed into the core of the dome, it flowed out from under the surrounding beds in the manner described by Nettleton.[3] This placed the overlying strata in tension and finally fractured them. Later the sediments found above 14,000 feet were deposited. Movement of the salt plug continued during their deposition, but the influence of the salt movement was confined to a smaller and smaller area.

ACKNOWLEDGMENTS

The author is indebted to the Geophysical Research Corporation and Amerada Petroleum Corporation for permission to publish this paper. Mr. W. A. Carruth prepared the figures.

[3] L. L. Nettleton, "Fluid Mechanics of Salt Domes," Bulletin A.A.P.G. Vol. 18, No. 9, Sept. 1934, pp. 1175–1204.

GRAVITY METER SURVEY OF THE WELLINGTON FIELD, LARIMER COUNTY, COLORADO*

JOHN H. WILSON†

ABSTRACT

The results of a gravity meter survey across the Wellington Field, Larimer County, Colorado, both before and after elimination of the regional effect is presented in relation to the subsurface structure of the field. The method of eliminating the regional effect is shown.

This information is presented as a "case book" type, illustrating an anomaly related to local structure that is almost obscured by strong regional gradients.

INTRODUCTION

The research physician keeps a book of interesting or unusual cases. The relationship recorded between certain symptoms and certain diseases may help in the diagnosis of future cases of similar character. The geophysicist uses a similar procedure in making analogies between new anomalies found with those occurring over known structures. The survey of the Wellington Field is presented as a type suitable for the geophysicist's "case book."

At the start of a survey of the Denver Basin in 1940, the Wellington Field, Larimer County, Colorado, situated on an anticline with a closure of approximately 800 feet was selected as a typical mountain fold on which to run an experimental survey. It also turned out to be typical of those cases where local structure produces an appreciable anomaly that is almost obscured by strong regional gradients.

A structural map of the Wellington Field, contoured on the top of the Muddy sand, is shown in Fig. 1. The depth to the datum bed is approximately 4,250 feet on top of the structure.

FIELD SURVEY

The survey was made with a gravity meter designed by F. M. Kannenstine and associates which utilizes an electrical-circuit indicator device. It was adjusted to a sensitivity of 0.025 milligals per scale unit.

The field work was done by a party of the Independent Exploration Company under the supervision of E. H. Clark, party chief, in August 1940. Elevations were run by transit and stadia surveys, the closures

* Presented at the Annual Meeting, Houston, Texas, April 1, 1941.

† Independent Exploration Co., Houston, Texas.

being held to such limits that no significant error was introduced into the final result.

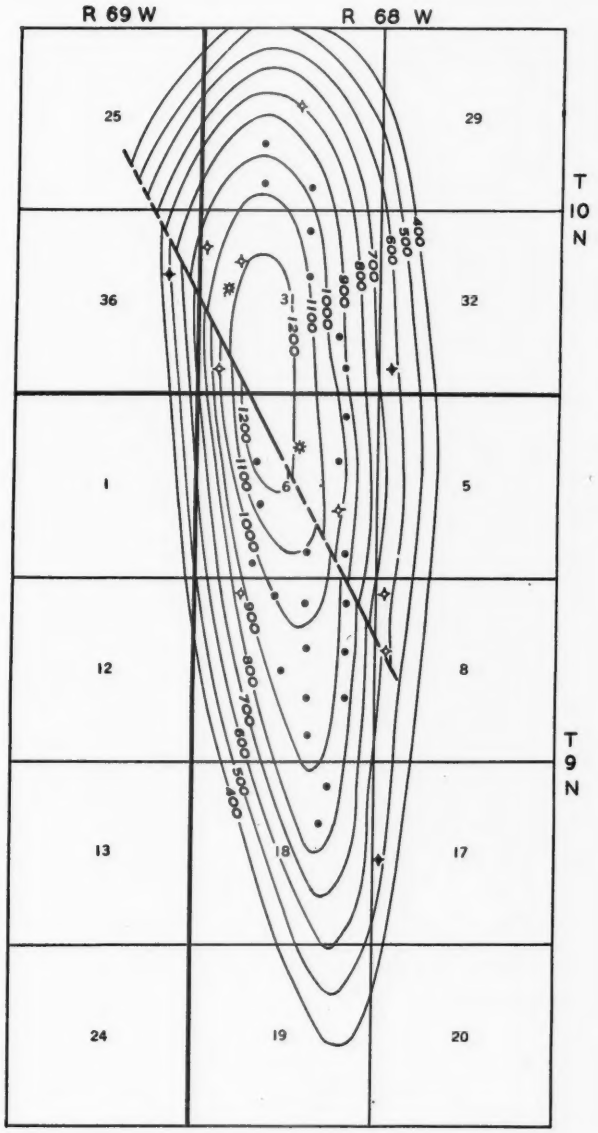

FIG. 1. Wellington Oil Field, Larimer Co., Colorado, subsurface structural map contoured on Muddy Sand.

The results of the field survey are shown in Fig. 2. The numbers at each station represent the observed relative gravity force in units of 0.1 milligal, which have been corrected in the usual manner for changes in elevation and latitude. The isogam interval is two units or 0.2 milligal. No regional corrections have been applied on this map. The ap-

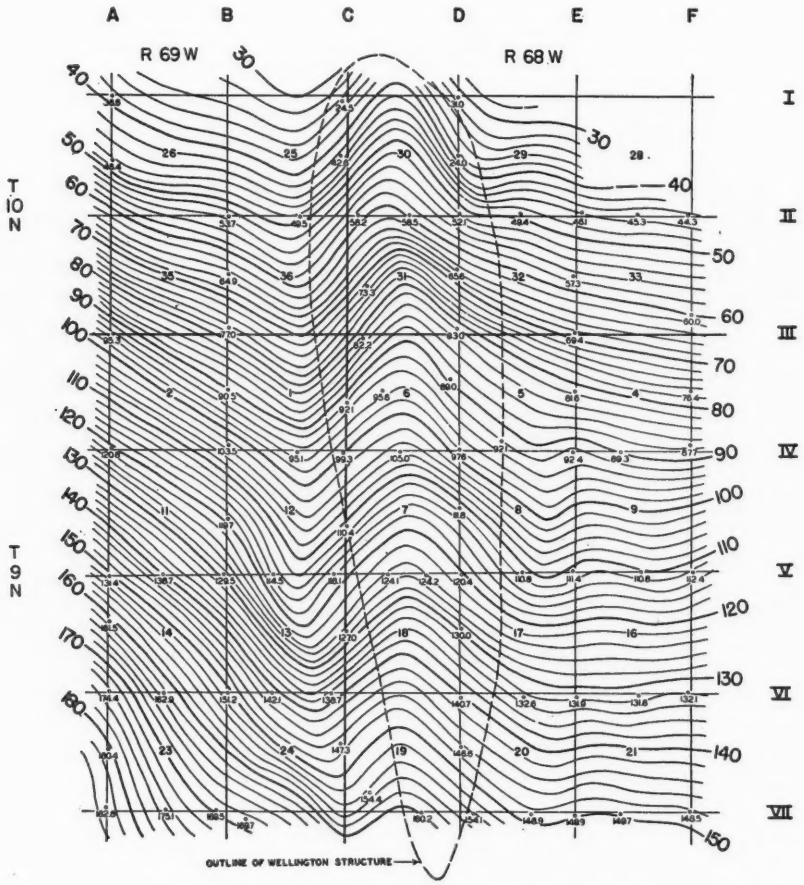

FIG. 2. Observed gravity, contoured at 0.1 mg. interval.

proximate outline of the lowest closing contour of the structural map is shown by a dashed line. It will be noted that the location of the structure is indicated by a positive anomaly of about 1.0 milligal, but also that is rather difficult from simple inspection to see that it indicates the structure shown in Fig. 1.

REGIONAL CORRECTIONS

To the southward of this area there is a large regional maximum anomaly, which on the basis of depth calculations, general character, and knowledge of the geology of the district, is believed to be due to density variations within the basement rocks and thus not necessarily related to the local structure.

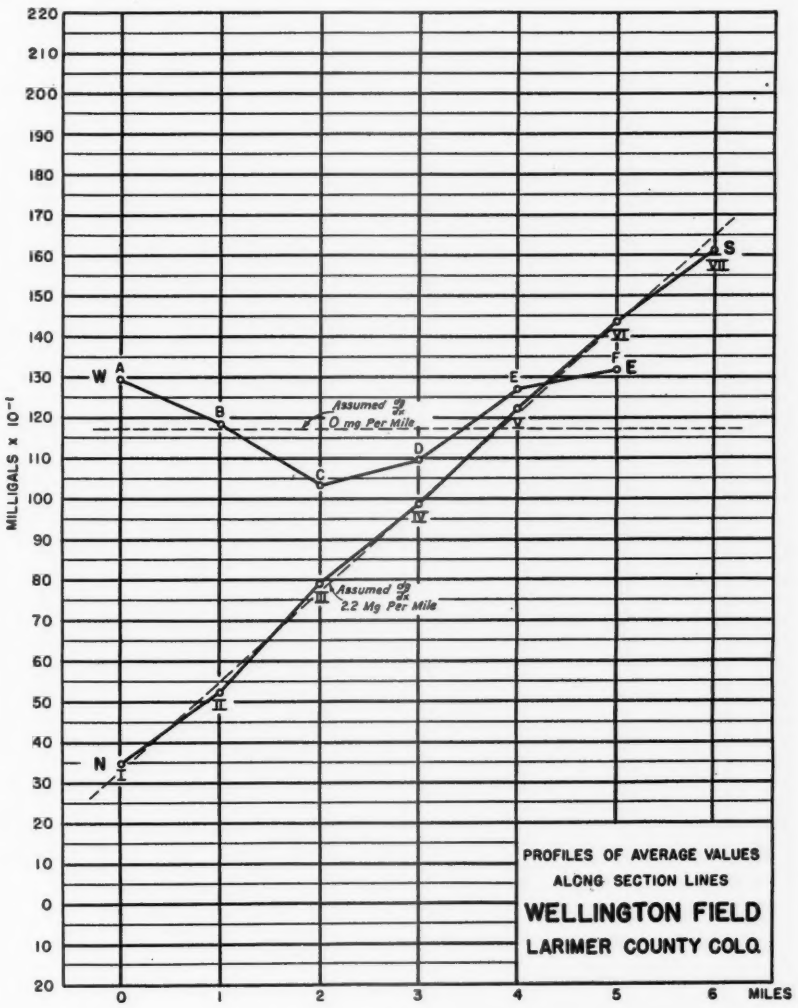

FIG. 3. Derivation of regional correction from N-S and E-W profiles.

It is obvious from inspection of the regional map that the Wellington area lies on the north flank of this regional anomaly and that the effect of the regional anomaly is added to that produced by the

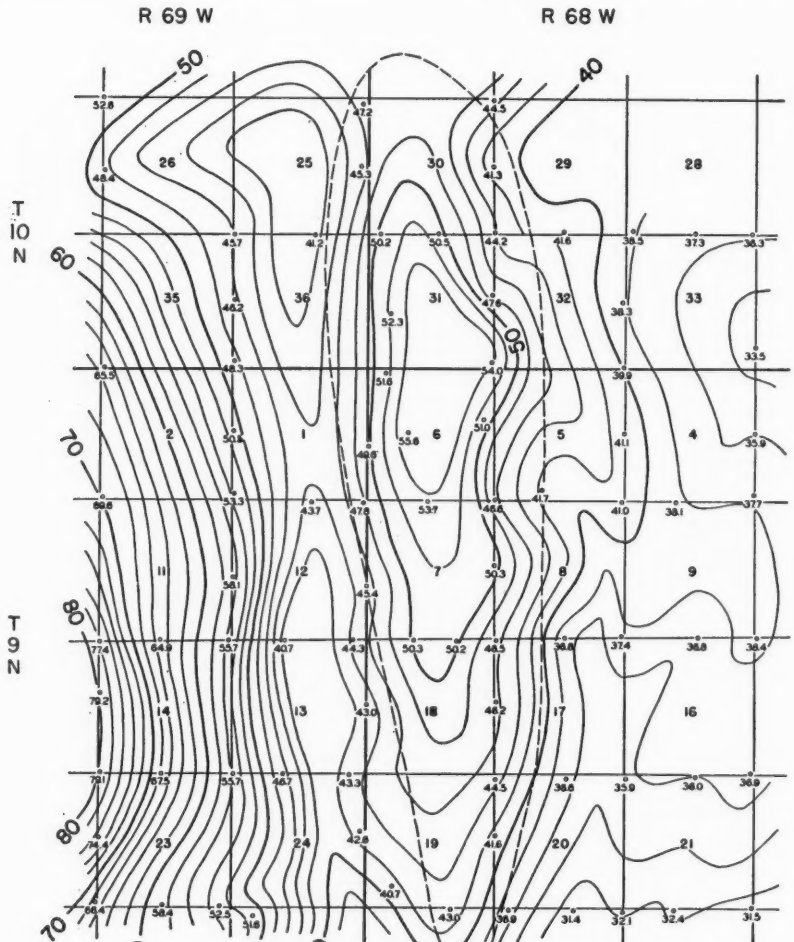

FIG. 4. Adjusted gravity contoured at 0.2 mg. interval. Regional gradient of 2.2 mg. per mile south has been subtracted from observed gravity of Fig. 2.

local structure. It was decided to eliminate the regional effects and compare the residual values with the structural data.

The method of calculating the regional effect used is applicable for

very limited areas only and is best adapted for sectionized country where roads are generally one mile apart in the cardinal directions. Averages of equally spaced stations were taken across the map along the section lines, both north and south and east and west. Where observations were missing at the regular spacing, contoured values were used. The average values obtained along each section line were plotted in profile form as shown in Fig. 3. We were able to obtain straight line approximations of the resulting curves which indicated the north-south component of the regional anomaly increases to the south at the rate of 2.2 milligals per mile and the east-west component, taking into account some data outside of the limits of the maps, was zero. Accordingly a "straight line" correction of 2.2 milligals per mile increase to the south was applied. In other areas in this region, curved line corrections were sometimes used to better advantage.

The residual map resulting from the regional correction is shown in Fig. 4. It will be noted on comparison of this map with that of the subsurface structure that a good general agreement in shape is obtained, also that the axis of the structure coincides closely with the axis of the anomaly and that the highest closing isogam is in nearly the same position as the highest closing structural contour. Also there appears to be some reflection of the fault shown on the structural map.

This study was part of a larger investigation into the interpretation of gravity anomalies in which it was assumed that the method of regional correction which gave the closest agreement between known structure and the corresponding anomaly was the best method to use on anomalies in the same area where structural conditions were unknown.

ACKNOWLEDGMENTS

Thanks are due Independent Exploration Company of Houston, Texas for permission to publish these data, to O. B. Manes and S. R. Normand for assistance in preparation of maps and to Petroleum Information, Incorporated, of Denver, Colorado, for permission to reproduce the structural map of the Wellington Field.

RELATION OF GRAVITY TO STRUCTURE IN THE NORTHERN APPALACHIAN AREA*

L. L. NETTLETON†

ABSTRACT

A series of gravity stations at approximately one mile intervals has been established eastward from Pittsburgh extending across the Appalachian Mountains and onto the pre-Cambrian outcrops of the Piedmont. The large folds and faults of the steeply folded region have small or negligible gravity anomalies. This is attributed to a uniform density of the rocks involved which is verified by "density profiles."

There has been much speculation as to the relation of gravity to tectonics and present geology in the northern Appalachian area. This speculation is reviewed briefly and some relations not previously mentioned are pointed out. The major and more continuous gravity features correspond closely with the trends of Appalachian folding, as shown by a map of gravity contours superposed on the relief map of the northern Appalachian area. However, it seems probable that the source of the primary gravity features is in mass distributions rather deep within the earth's crust, which must have their origin in the tectonic forces which caused the Appalachian uplift but are not superficially evident from the surface geology of the area. Some smaller features may be related to structural or lithologic units indicated by the surface geology.

INTRODUCTION

The economic purpose of the gravity measurements on which this paper is based was to give a thorough field test to a new instrument which was destined for a long period of foreign service. It was felt that at the same time data of considerable academic interest could be obtained with comparatively little additional cost. Therefore, the field tests were conducted in such manner that they gave a continuous gravity traverse across the Appalachian Mountains. For the most part the measurements are on a traverse along the Lincoln Highway (U.S. 30) from near Pittsburgh to beyond Gettysburg. Thus, the traverse crosses the Allegheny Plateau, the band of steeply folded sediments, the Triassic Trough, and reaches onto the pre-Cambrian rocks of the Piedmont.

THE GRAVITY MEASUREMENTS

The measurements were all made with the Gulf gravimeter.(24)‡ This instrument is of the unastatized, or linear type, and is particularly well suited for direct measurement of rather large gravity differences. The instrument was calibrated to a precision of better than

* Presented at the meeting of the Society of Exploration Geophysicists, Houston, April 1, 1941.

† Geophysicist, Gulf Research & Development Co., Pittsburgh, Pa.

‡ For numbered references see Bibliography.

0.5% by comparison with a gravity difference carefully established with Gulf pendulum apparatus.(21)

The framework of the gravity measurements is a series of "subbases" which were set out at intervals of five to eight miles. These subbases were first established by a series of "looping" observations as indicated by Fig. 1. For instance, an observation was made at station 8, then the instrument was taken ahead to station 9, back to station

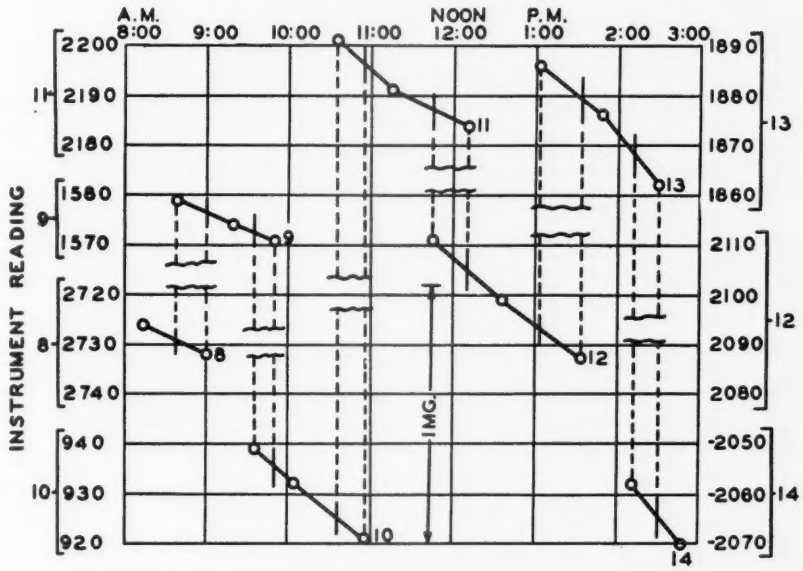

FIG. 1. Gravimeter drift curve for sub-base observations.

8, ahead to station 9, on ahead to station 10, back to station 9, ahead to station 10, etc. These observations gave two determinations of the gravity difference between each pair of stations, as is indicated by the dotted vertical lines on the figure. Intermediate stations between the subbases were established by simply reading the gravimeter at a subbase, then at each of the intermediate stations and then at the next subbase along the road as indicated by Fig. 2. A lateral traverse of subbases was carried to Washington, D. C. where ties were made into the primary U.S.C. & G.S. gravity station at the Bureau of Standards. Also ties were made into a few government field stations in the vicinity of Washington. These connections established absolute gravity values for all of the observations.

The precision of the gravity measurements is indicated by the scales of Figs. 1 and 2. From the regularity of the drift curves as shown by these figures the probable precision of the gravity differences should be materially better than 0.1 mg. That a precision of this order of magnitude was actually achieved is further indicated by two closed loops of subbases. A branch loop was run from Gettysburg northeasterly to Harrisburg and southwest to Chambersburg. This loop with

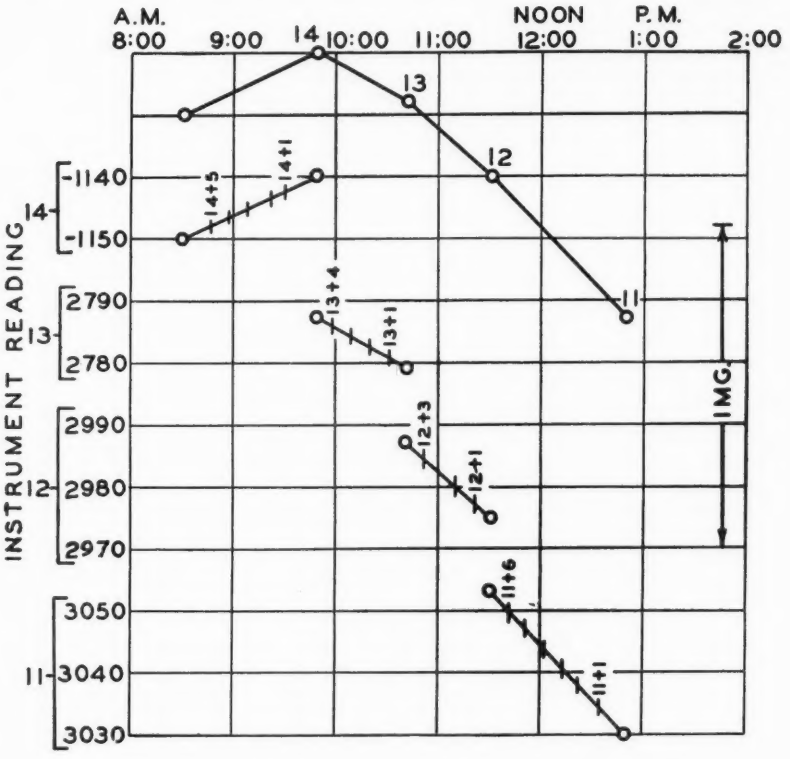

FIG. 2. Gravimeter drift curve for observations of intermediate stations.

a total length of 109 miles had a closure error of 0.05 mg. A second loop from Gettysburg south to Frederick and back through Hagerstown to Chambersburg, with a length of 105 miles, had a closure error of 0.17 mg.

Through the procedure outlined above absolute gravity values were established at approximately one mile intervals from Greenburg along the Lincoln Highway to its intersection east of Gettysburgh with

Pennsylvania Highway 94, and thence southward through Hanover to the Maryland line. Errors in the relative gravity differences of these stations are probably less than 0.1 mg.*

AUXILIARY DATA

In order to make the usual reductions it is, of course, necessary to establish the elevation and latitude of all the stations. The elevations for the most part were determined with respect to the center line of the highway for which elevations were furnished by the Pennsylvania State Highway Department. The stations not on a highway for which elevations were available were all set at points at which elevations were given on topographic maps. The regular U.S.C. & G.S. topographic sheets at scale 1:62,500 cover the entire area. Stations were carefully located on these sheets and their latitudes and longitudes determined directly from the plotted positions.

REDUCTIONS

The various reductions were carried out in the same manner as is used by the U.S.C. & G.S. for the reduction of their pendulum stations. In this method of reduction the theoretical value of gravity at the position and elevation of the station is calculated and the difference between the measured value and the theoretical value is the anomaly. Thus the "free air" anomaly is the difference between the measured value and the theoretical value calculated with the "free air" correction only. Similarly the Bouguer and isostatic anomalies are the differences between the actual value and the theoretical value calculated with the Bouguer and isostatic corrections, respectively. All calculated values are based on the "International" gravity formula. These three anomaly curves are shown by Fig. 3.

The U.S.C. & G.S. has kindly cooperated by calculating the isostatic corrections for all of the subbases and some of the intermediate stations of the traverse so that for these stations the isostatic and the complete Bouguer† calculations are available. From the regularity of

* Detailed tables of the numerical data of the gravity measurements and their reduction are not included but will be supplied by the Gulf Research & Development Co. to interested parties requesting them.

† The Bouguer reduction was made according to Bullard's method[20] in which the topography is first considered as a flat infinite sheet so that the calculated gravity effect is simply the elevation times a constant (with a small additional term which takes care of the curvature of the earth). A second part of the calculation takes care of the undulations of the surface or the "terrain effect." This effect always raises the

the Bouguer anomaly curve it is evident that calculation of isostatic reductions for all of the stations would not materially change the isostatic anomaly curve from that which is shown by the stations for which the complete calculations were made. The Bouguer and isostatic curves are for a density of 2.67 for all rock above sea level.

GEOLOGY

A geologic cross section of the area traversed by the gravity profile, as shown on Fig. 3, has been worked out principally from the surface geology as shown on the new geologic map of Pennsylvania. While the surface contacts and dips for this profile are taken quite accurately from surface information, the interpretation of these data at depth is, of course, speculative and uncertain. As a matter of simplicity the thicknesses of the various formation units have been taken as substantially constant throughout, while in fact there are probably material lateral variations in the thicknesses of these units.

INTERPRETATIONS

There are two aspects of any attempt to evaluate the subsurface implications of the gravity results. The first is with respect to what may be called "local features"; that is, the effect of the individual structural details on gravity. It is for this purpose that the present profile is particularly well adapted because of the close spacing of the individual stations. On the other hand there are certain very broad or "regional" features, the causes of which are undoubtedly at considerable depths within the earth's crust. For consideration of these features stations as close as one mile apart are not required, and the stations of the profile for which the complete isostatic reductions have been calculated are close enough.

LOCAL ASPECTS OF INTERPRETATION

The most striking feature of the results as indicated by the anomaly profiles of Fig. 3 is the very slight gravity effect of large structural features. Thus the Schellsburg anticline and the large faults near McConnellsburg have practically no effect on the isostatic or Bouguer

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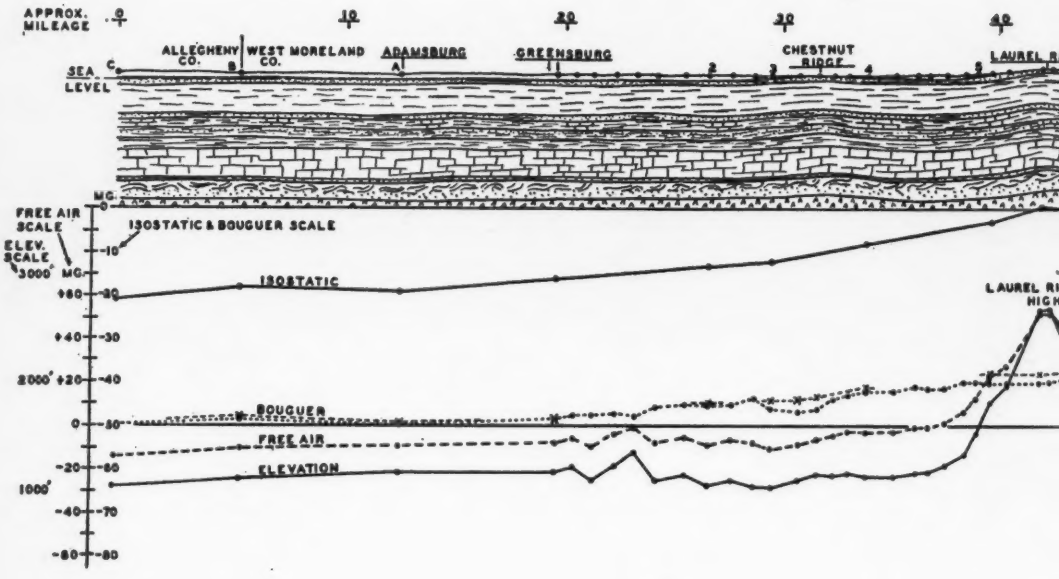
Bouguer and isostatic anomaly values. For most of the stations of this survey this terrain effect was not calculated but this quantity is available for all stations for which the isostatic reductions were made. The occasional Bouguer values including terrain calculations are shown on Fig. 3 by crosses and an intermittent dotted line above the Bouguer anomaly line.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ELEV. SCALE
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ISOSTATIC & BOUGUER SCALE
ISOSTATIC
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HIGH
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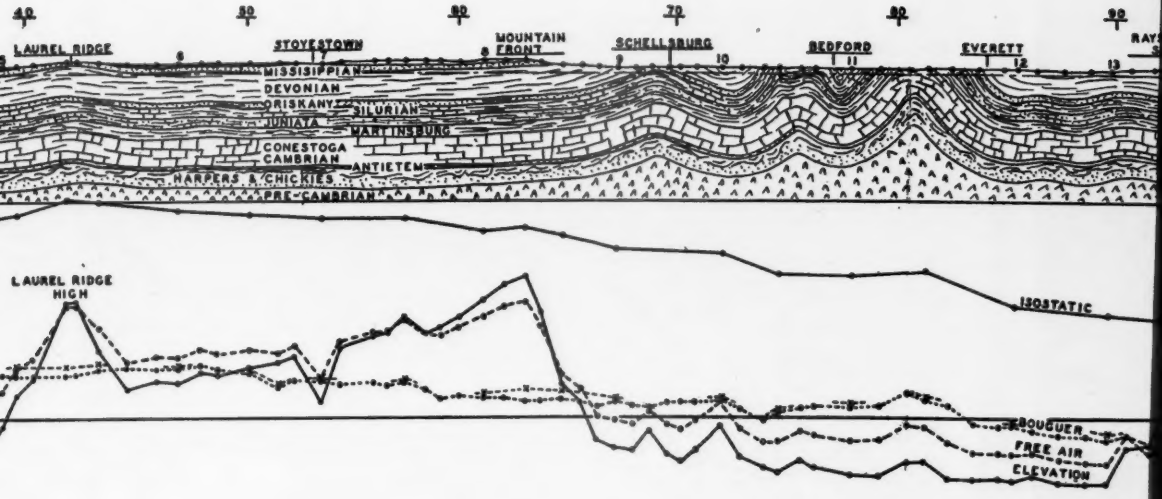
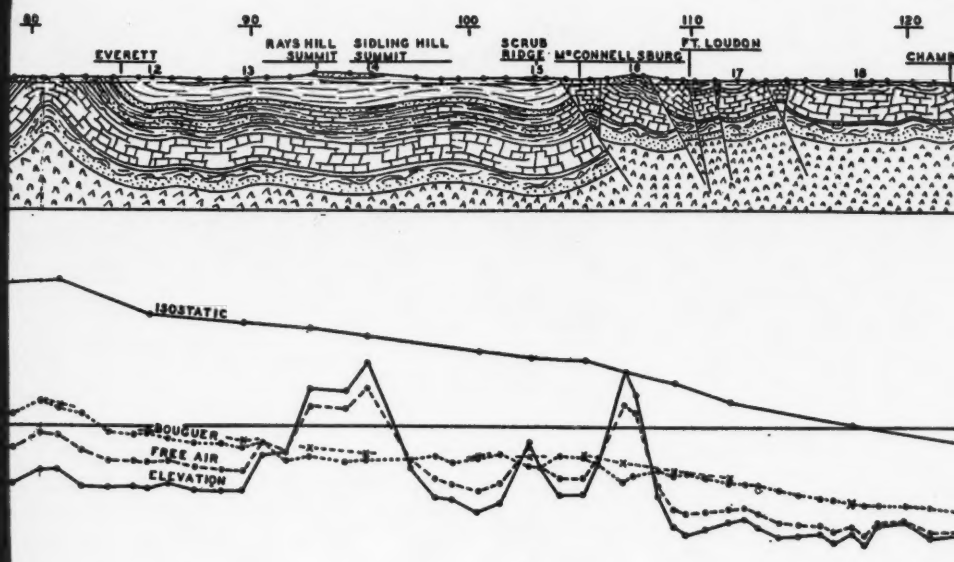
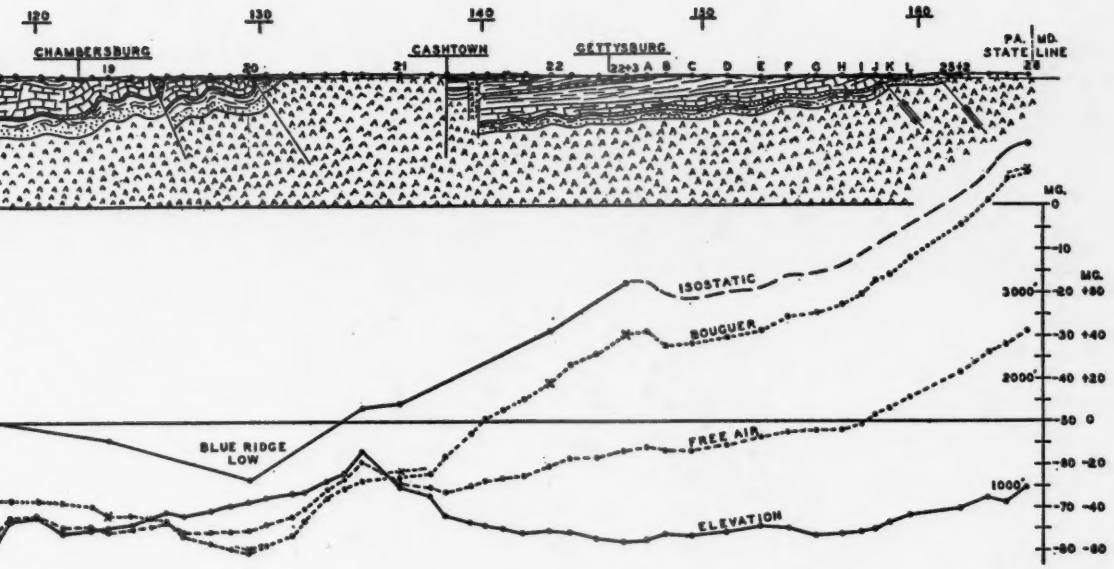


FIG. 3. Geologic section, gravity anomaly curves and elevation profile, Lincoln



and elevation profile, Lincoln Highway gravimeter traverse.


120
130
140
150
160
CHAMBERSBURG
CASHTOWN
GETTYSBURG
PA. STATE
MD. LINE
19
20
21
22
22+3
A
B
C
D
E
F
G
H
I
J
K
L
23+2
26
MG.
0
10
20
30
40
50
60
70
80
3000'
2000'
1000'
+80
+40
+20
0
-20
-40
-80
ISOSTATIC
BOUGUER
FREE AIR
ELEVATION
BLUE RIDGE LOW

UNIV. OF MICH.

gravity curves, while the very large structure between Bedford and Everett has a local gravity effect of only some three or four mg. This is a very slight effect for such an enormous structure. (Note that the geologic section is drawn with equal vertical and horizontal scales and the structural relief of this feature is of the order of 10,000 ft.)

From the above it seems that the only reasonable explanation of the lack of much larger local gravity effects is that the densities of the rocks involved in the structures and faults must be quite uniform. Further evidence on the density can be obtained from the Bouguer anomaly curve over individual topographic features. By making the Bouguer corrections for different densities, an indication of the true density of the topography contained within the topographic unit is given by the density which gives the smoothest reduced curve across the variation in elevation. (This is the same as the procedure for making "density profiles" (25) to determine densities for use in reducing gravimeter field observations in normal prospecting procedure.) Density profiles made for the topographic features at Laurel Ridge, the Allegheny Front, and Tuscarora Mountain (between McConnellsburg and Fort Loudon) all indicated that the density used for the reduction of the Bouguer curve as given on Fig. 3 was smoother than the curve resulting when the density was one-tenth higher or lower. This indicates that the density of the rocks within the range of the elevations of each topographic feature is rather close to 2.67 and, since the different density profiles involve different parts of the geologic section, it constitutes rather strong additional evidence that the densities of the sediments involved in the folds and faults are quite uniform and with a value of about 2.67. Thus, the fact that gravity expressions of local structure in the Paleozoic sediments are weak or absent is adequately explained.

From measurements of specific gravities of the crystalline basement rocks in the Piedmont area of Virginia, Woollard (10, p. 319) concluded that the average densities of these rocks is around 2.67. A "density profile" across the topographic feature west of Cashtown (station 21) indicates a density of 2.87. This is an aporhyolite (arc of the Pennsylvania geologic map). From this rather meagre evidence it seems probable that the density of the basement rocks is not much greater than that of the overlying sediments and therefore gravity will not indicate whether or not the basement rocks are involved in the folds. This question might be solved with suitable magnetic surveys.

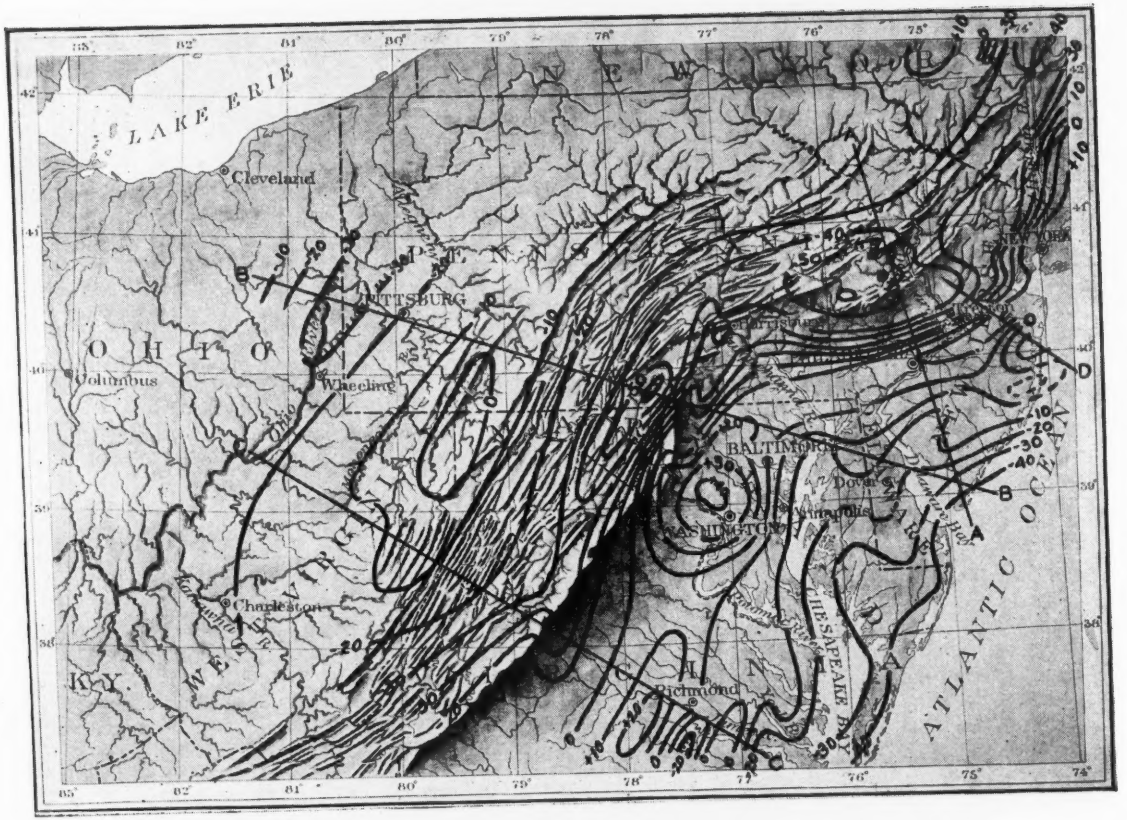


FIG. 4. Isostatic gravity contours superposed on relief map of the northern Appalachian area. Contour interval 10 mg. (Photograph courtesy U. S. Geological Survey.)

REGIONAL ASPECTS

When the results from the Pennsylvania gravimeter traverse are combined with all U.S.C. & G.S. pendulum measurements, there is enough control* to give a fairly satisfactory gravity map of the northern Appalachian area. The gravity contours (isostatic anomaly values for 113.7 km. depth of compensation) are shown in Figs. 4 and 5. In Fig. 4 the gravity contours are superposed on a photograph of a relief map of the area to show the rather striking parallelism of the gravity and topographic trends; Fig. 5 shows the relation of gravity to the

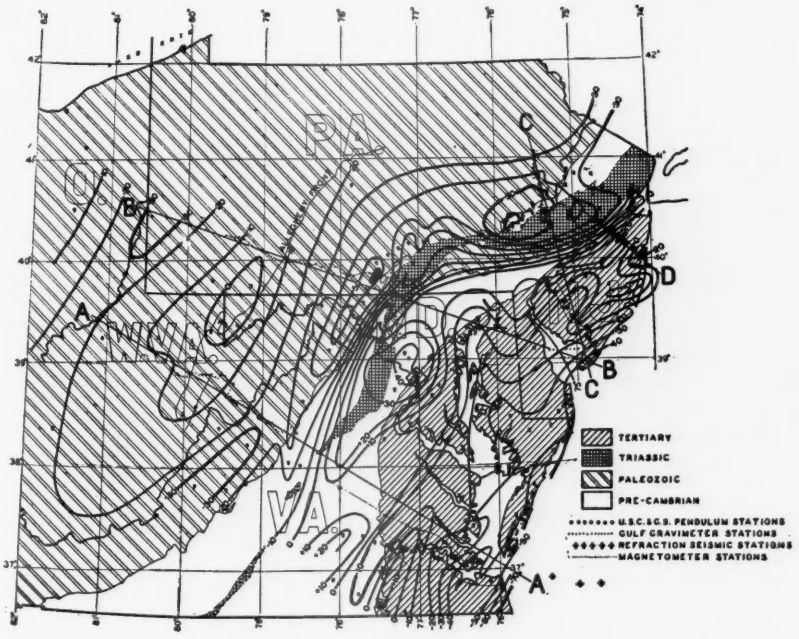


FIG. 5. Relation of isostatic gravity contours to generalized surface geology of northern Appalachian area (contour interval 10 mg.).

principal geologic provinces of the area. Fig. 6 shows isostatic gravity profiles along the four lines indicated on Figs. 4 and 5.

Profile B includes the detailed Pennsylvania profile and is extended eastward approximately through Washington to the Atlantic Coast where fair control is available from government gravity stations.

* Additional control will be available from the transcontinental gravity traverse carried out last summer by G. P. Woollard, which runs roughly parallel with, but north of the present traverse. Isostatic values for this work are not yet available.

area. Contour interval 10 mg. (Photograph courtesy U. S. Geological Survey.)

Profile A to the south extends from the Ohio River across West Virginia and Virginia to the Atlantic Ocean at Cape Henry. Gravity control of the eastern end is fairly good as it includes a special line of

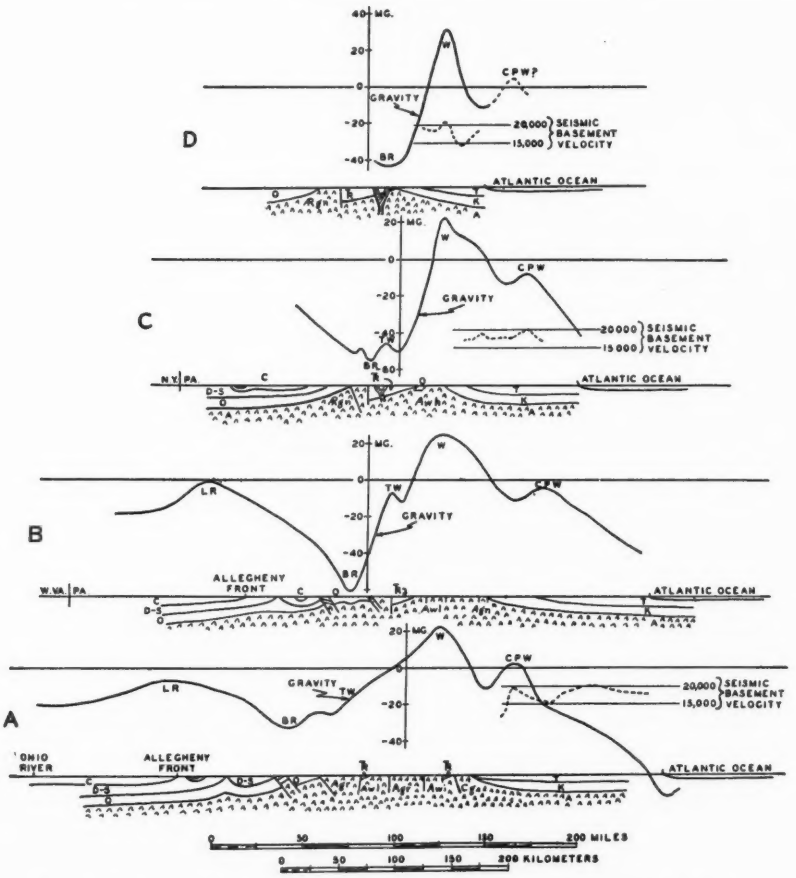


FIG. 6. Gravity and geologic profiles across the northern Appalachian area. (Locations of profiles shown on Figs. 4 and 5.) T = Tertiary; K = Cretaceous; TR = Triassic; C = Carboniferous; D-S = Devonian and Silurian; O = Ordovician; A, Awl, Awh, Agn = pre-Cambrian; LR = Laurel Ridge High; BR = Blue Ridge Low; W = Washington High; TW = Triassic Wrinkle; CPW = Coastal Plain Wrinkle.

U.S.C. & G.S. pendulum stations across the Coastal Plain (6). A line of seismic refraction stations also has been set out along this gravity profile and is extended eastward (1) by submarine stations on the Continental shelf. The control of the western part of this profile is

given in part from results of gravimeter measurements* in West Virginia and Virginia.

Profile C extends across the area of close gravity stations in eastern Pennsylvania and southward to Cape May, New Jersey.

Profile D is quite close to C, but has been included as this is the Barnegat Bay traverse of seismic refraction stations (3) and the subsequent gravity stations.

The geologic sections under the several gravity profiles are based on the geologic map of the United States (scale 1:2,500,000).

In order to correlate the gravity results with other geophysical work in the general area, the profile lines have been chosen to include the traverses of seismic refraction and magnetic surveys across the coastal plain. Seismic velocity of the basement rocks from this work (1, 3, 4) is shown by dotted curves near the eastern ends of profiles A, C and D.

It is apparent from the maps and profiles that the larger gravity features are quite continuous and are closely parallel with the mountain folding, and therefore must be closely related to the regional tectonics of the area. There are some smaller, less continuous features which probably are to be explained in terms of more local structural or lithologic units. For convenience in discussion, the several persistent features of the regional gravity as indicated by the several profiles of Fig. 6 and the contours of Figs. 4 and 5 will be discussed under the following names:

The western high of the Pennsylvania profile (Profile B) and its southward extension, as shown on profile A, will be called the Laurel Ridge high. (LR on Fig. 6)

The sharp minimum to the east will be called the Blue Ridge low. (BR on Fig. 6)

The small feature at the western edge of the Triassic, as shown particularly on profile B, will be called the Triassic wrinkle. (TW on Fig. 6)

The principal maximum with large positive values which appears on all the profiles will be called the Washington high as its strongest expression is at the city of Washington. (W on Fig. 6)

The low and high to the east as shown on profiles A, B and C and questionably on profile D will be called the Coastal Plain wrinkle. (CPW on Fig. 6)

* These measurements, made by the Gulf Research & Development Company in the fall of 1939, were reported on by S. Hammer at the American Geophysical Union meeting in Washington April 30, 1941 and will be published in the transactions of that meeting.

For the most part these features have been known for some years from the pendulum control, and their possible significance has been the subject of considerable discussion and speculation (2, 5, 6, 8–11, 13, 15, 19). The new data of the present work have added useful detail but have not materially changed the general gravity picture of the area. However, it seems worth while to review and summarize the previous speculations and perhaps to point out a few relations between gravity and the general geology which are not included in the papers mentioned. This is attempted in the following paragraphs.

From the gravity map and profiles the following conditions seem apparent. 1) The Laurel Ridge high is only a little west of the center of the Appalachian Basin and corresponds roughly with the maximum thickness of sediments (18). 2) The Blue Ridge low is near the eastern edge of the sediments, but in going from south to north it shifts eastward so that on profiles C and D the minimum is distinctly east of the east edge of the Paleozoic sediments. 3) The steepness of the rise from the Blue Ridge low to the Washington high increases regularly toward the north and at the same time the width of the exposed crystalline rocks decreases. 4) The Triassic wrinkle seems to be associated with the belt of Triassic sediments and intrusives, but in going north the position of this belt moves westward with respect to the Blue Ridge low and the Washington high. 5) The sharpness of the Washington high increases regularly toward the north as the width of the exposed band of crystalline rocks decreases. 6) The distance from the westerly boundary fault of the zone of Triassic sediments to the low and high of the Coastal Plain wrinkle is substantially constant, although the positions of these two features with respect to the Blue Ridge low and the Washington high are variable.

Any reasonably complete interpretation of the gravity in terms of the Appalachian tectonics would include an explanation of the above observations. It is probably impossible to even approach a complete explanation of these facts in view of the present meager knowledge and understanding of the geology and deep tectonics of the area.

A theory of crustal down-warping associated with geo-synclinal areas has been developed by Vening Meinesz (28) and Hess (23) in connection with the great negative gravity anomalies and ocean deeps associated with the island arcs of the East and West Indies. From this theory we would expect a gravity minimum more or less centrally located with respect to the synclinal area. Skeels (26) has investigated gravity anomalies in sedimentary basins in different parts of the world

and finds a general agreement between the gravitationally low area and the area of thick sediments. The gross relations of gravity and geology in the Appalachian basin are not as would be expected by analogy with the areas of the studies just mentioned for the principal gravity minimum (the Blue Ridge low) is near, or even east of, the edge of the sediments and the center of the basin is gravitationally high (the Laurel Ridge high). A theory of mountain building which would account for the gravity minimum being near the edge of the sedimentary basin has been proposed by Gunn (22) and in some ways the relations between gravity and geology in the Appalachian region resemble those which might be expected from this theory. However, a major consequence of that theory is a maximum thickness of sediments and a corresponding gravity minimum near the boundary of the sedimentary basin. The required thickening of the sediments toward the edge of the basin seems to be contrary to the actual geology of the area.

From the gross relations between gravity and geology mentioned, it seems probable that the Appalachian geo-syncline is not as simple a feature in its fundamental tectonics as are the areas and theories of the studies mentioned above. Its present geological aspect is the end result of deformations taking place over a very great span of geological time and it is quite probable that whatever gravity condition may have existed, say at the close of the Pennsylvanian when it was a simpler sedimentary basin and possibly comparable with the basin areas of the above mentioned studies may have been largely obliterated by isostatic adjustment since that time or by the causes or the mass distribution resulting from the tremendous thrusting and other tectonic forces and movements which have occurred in more recent geologic epochs. At present it seems probable that the principal causes of the gross features of the present gravity picture, such as the Blue Ridge low and the Washington high, are in density contrasts rather deep within the earth's crust and are not to be explained in terms of density contrasts among the sediments or between sediments and basement rocks of the type exposed in the Piedmont. This is only partly in line with Woollard's suggestions (10, p. 322) that: 1) The gravity trough reflects a basin of low density sediments covered by overthrust crystalline rocks; 2) the gravity trough is due to the tectogene (i.e. crustal down-buckle) associated with a former Appalachian system of island arcs; or (3) the trough represents the effects of late Paleozoic compressional forces which fractured the crust and over-

thrust the eastern member, so that the overridden member was forced down into the substratum.

The first of these suggestions seems to be ruled out by the evidence that there is no substantial density contrast between the Paleozoic sediments and the crystalline rocks of the Piedmont. The second and third suggestions seem possible but direct evidence for confirmation is lacking as these involve movements of deep parts of the earth's crust and the possible density contrasts and masses involved have no simple counterparts or effects which are directly observable at the surface.

It is more probable that features such as the Triassic wrinkle and the Coastal Plain wrinkle are associated directly with density contrasts of the sedimentary or basement rocks at or relatively near to the present earth's surface.

The Triassic wrinkle may be an expression of a rather large body of intrusive basic rock from which the surface flows of Triassic diabase within the band of Triassic sediments are derived. The gravity feature does not seem to be a simple expression of lower density of the sediments within the Triassic trough contrasted with heavier adjacent rock. At least, on the detailed profile (Fig. 3) the high of the wrinkle comes in the central part of the belt of Triassic sediments, whereas a gravitationally low region would be expected there if the source were in the light sediments. A similar failure of the anticipated simple relation between the Triassic trough and gravity results was shown by the rather detailed net of U.S.C. & G.S. pendulum stations in western New England (15).

The rather extensive geophysical work across the Coastal Plain has been invoked particularly by Woollard (10) in attempts to get clues as to the meaning of the gravity results. Attempts have been made to correlate the seismic velocity of the (probably) metamorphic basement rocks under the Coastal Plain with their density and resulting gravity anomalies and thus work out the lithology and geology of the basement. The data on which these correlations have been attempted are assembled in Fig. 7. In this figure the various quantities have been plotted at uniform vertical scales to bring out the relative quantitative relations of the different traverses and at uniform horizontal scale with the left (northwesterly) ends lined up at the "Fall Line." (In the various original publications, the scales are different and some of these relations are not apparent). The basement velocity curves also are shown at the easterly ends of profiles A, C, and D (Fig. 5).

Three instances of more or less close agreement of gravity highs and basement velocity high are shown by these profiles. These are: 1) On the Fort Monroe profile (Fig. 7) there is a gravity high near the westerly end of the profile and a closely coincident basement velocity

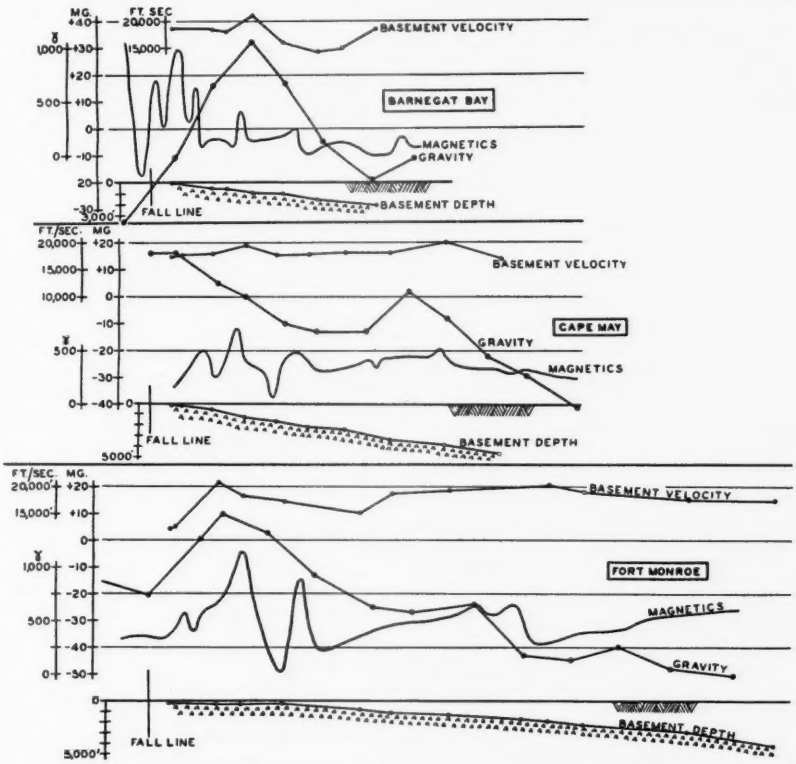


FIG. 7. Gravity, seismic velocity of basement, magnetic and basement depth profiles across the Coastal Plain, assembled from various publications of Ewing et. al. and Woollard and plotted to uniform scales. Magnetic profiles are smoothed from original observations.

high. This gravity high is the "Coastal Plain Wrinkle" of profile A (Fig. 6). 2) On the Cape May Profile (Fig. 7) there is a gravity high near the center of the profile and a seismic velocity high somewhat farther west. This gravity high corresponds to the "Coastal Plain Wrinkle" of profile C (Fig. 6). 3) On the Barnegat Bay profile (Fig. 7) there is a very large gravity high near the center of the profile which corresponds with a "one station" seismic velocity high. This gravity high corresponds with the "Washington High" of profile D (Fig. 6).

It may or may not be reasonable to attempt to draw conclusions as to the geologic and lithologic nature of the basement rocks from these coincidences. In the first two instances, the features are of somewhat similar magnitude and the two coincidences (although in the second case the "coincidence" is somewhat forced) may indicate the continuity of a geologic unit from one profile to another (i.e. from the Fort Monroe profile to the Cape May profile). In the third instance, the gravity feature involved is entirely different in magnitude and in its relation to Appalachian tectonics and it seems unreasonable to attach a similar significance to the coincidence and to imply the continuity of the geologic unit to that feature. If there is a similar feature on the Barnegat Bay profile, it is at the extreme eastern end of the profile, where the "Coastal Plain Wrinkle" is largely inferential as part of it would be off-shore, and there does seem to be a suggestion of a coinciding rise in the basement velocity at this end of the profile.

From all the above discussion it seems desirable to consider that there are two orders of magnitude to the gravity features of the northern Appalachian Area. First there are the very large primary features, i.e., the Washington High, the Blue Ridge low and possibly the Laurel Ridge high, which must result from deformations rather deep within the earth's crust and which probably cannot be definitely and simply associated with the visible surface geology. They may when properly understood and appreciated, lead to a much better understanding of the broad geological processes by which the Appalachian uplift reached its present position and attitude. Next there are the smaller, secondary features such as the Triassic Wrinkle and the Coastal Plain Wrinkle which are to be ascribed to much shallower and more local density contrasts and which, quite probably, can be related to lithologic or structural features evident from the surface geology. For most of these features, the present gravity control is far from adequate and it is quite probable that some of the continuities from one profile of data to another which are now inferred would not be found to stand up if reasonably complete gravity surveys were available over the areas between profiles.

ACKNOWLEDGMENT

The gravity work in particular, and much of the other material of this paper is the result of contributions by many members of the geophysical staff of the Gulf Research & Development Company as acknowledged by the following list: (1) Geologic section by R. W.

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GEOCHEMICAL WELL LOGGING*

W. R. RANSONE†

ABSTRACT

The collection of well cuttings, their analysis, and subsequent plotting as a Geochemical Well Log are briefly discussed. Numerous and varied examples of actual Chemlogs are presented. These illustrate specific applications, and also may be employed to form an opinion of the usefulness of the method.

INTRODUCTION

Geochemical Well Logging as a new development in Geochemical Prospecting has previously been mentioned by Horvitz,[1] McDermott[2] and Rosaire.[3] The illustrations accompanying this paper offer additional data of interest, and also serve to point out practical uses of a Geochemical Well Log. Recognition of these uses was the result of experience gained by making several hundred Chemlogs.

A DIRECT METHOD OF WELL LOGGING

The Geochemical Well Log indicates directly the Hydrocarbon content of the formation cut by the drill, by the chemical analysis of cuttings or cores collected during routine drilling. The Hydrocarbons analyzed are the Paraffine Series from Methane to Dodecane, common to most crude petroleum. Evolved hydrogen and other indirectly indicative substances may also be analyzed for.

SAMPLE COLLECTION AND ANALYSIS

A Chemlog is made by collecting cuttings or cores at suitable depth intervals. These samples are either analyzed at the well, using trailer mounted equipment, or sent to the main laboratory. In the latter case the samples are washed lightly to remove drilling fluid, placed in sealed glass jars and forwarded as quickly as possible to the laboratory.

The important point to emphasize here is that samples from all types of formation should be collected; this may necessitate special precautions to insure collection of very fine sands. It is also advisable to make a circulation depth correction since the depth error may be as

* Presented at the Annual Meeting, Houston, Texas, April 1, 1941.

† Geophysical Service Inc., Dallas, Texas.

[1] Leo Horvitz, GEOPHYSICS, Vol. IV, No. 3, July 1939, p. 210.

[2] Eugene McDermott, A.A.P.G., Vol. 24, No. 5, May 1940, p. 859.

[3] E. E. Rosaire, A.A.P.G., Vol. 24, No. 8, August 1940, p. 1400.

much as twenty feet in extremely deep holes. This correction is made in the same manner as for geological samples.

When the samples reach the laboratory they are weighed for analysis, and a separate portion set aside for determining the water content. They are then introduced into a low-pressure de-gassing apparatus where the desired constituents are extracted as gases. In order to facilitate the extraction process the sample is heated and digested with acid; this treatment increases the yield of Hydrocarbons manyfold. After extraction the gaseous sample is placed in the analytical apparatus for measurement. During the extraction and subsequent analytical processes the undesirable constituents are eliminated by suitable chemical traps. When the final computation is made the amounts of the pure constituents are known with an accuracy far exceeding the errors inherent in sampling.

DEPTH CONCENTRATION PATTERNS

When the analysis values are plotted at their appropriate depths on the Chemlog they frequently form depth concentration patterns which show when oil-bearing formations are being approached and penetrated by the drill.

The Hydrocarbons usually form depth concentration patterns related to the position of the well with respect to the accumulation. The Chemlog of a well located near the center of the accumulation exhibits a short Hydrocarbon leakage pattern; in other words, significantly high Hydrocarbon values will be encountered only a short distance above the accumulation. With wells located near the edge the reverse is true and high Hydrocarbon values may occur many hundreds of feet above the petroleum accumulation. Chemlogs of wells located entirely away from an accumulation show no significant Hydrocarbon values. This relationship of Hydrocarbon leakage appears to verify the evidence from surface Geochemical Prospecting.

Hydrogen forms depth concentration patterns which are quiet different from those formed by the Hydrocarbons. In general, high Hydrogen values indicate that the well is over or near the accumulation; if these values occur at shallow depths the well is favorably situated. Low Hydrogen values usually mean that the well is remote from the accumulation; but they may occur when the well is nearly over the center of the accumulation.

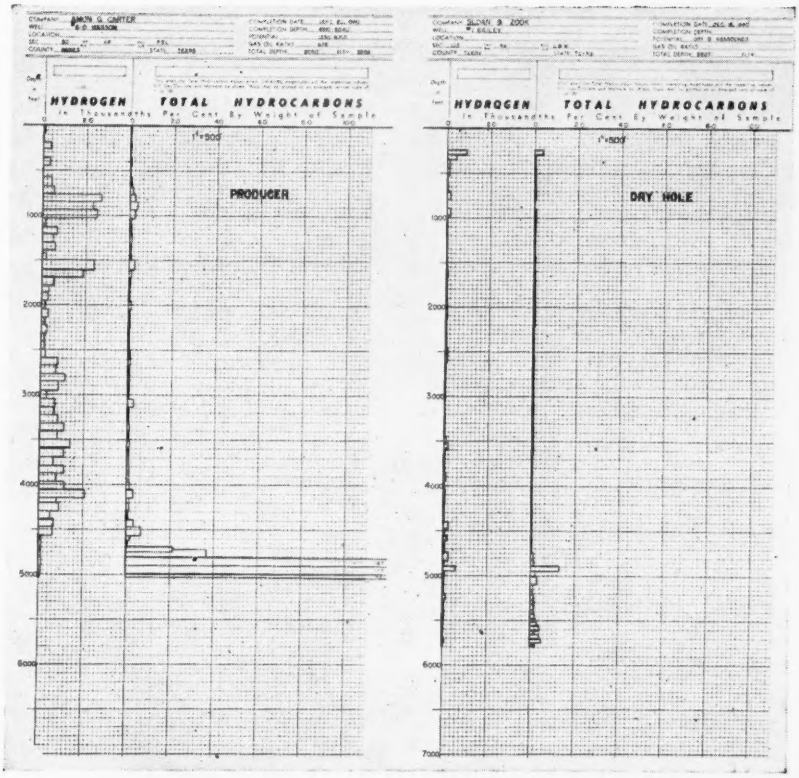


FIG. 1. *Amon G. Carter No. 6-D Wasson*

This is the Chemlog of an inside producing well in the Wasson Field, Gaines County, West Texas. It is an offset to the #5-D, famous as the discoverer of new deep producing horizons. This Chemlog is plotted to the vertical scale of 1 inch per 500 feet, the scale which is used while the well is being drilled. Note the favorable Hydrogen maximum occurring at 1000 feet. The first producing body is a gas sand at 4710 feet. Main production is oil from 4920 to 5040 feet.

FIG. 2. *Sloan & Zook Co. #1 Bailey*

This dry hole is located in Terry County, Texas, less than 30 miles from the Wasson well seen at the left. There are no significant Hydrogen and only one significant Hydrocarbon value suggesting no production in the section drilled or at greater depths. It is thought that the moderate value at 4890 feet, top of the lime section, may be a characteristic "kick" observable at this point in all West Texas wells.

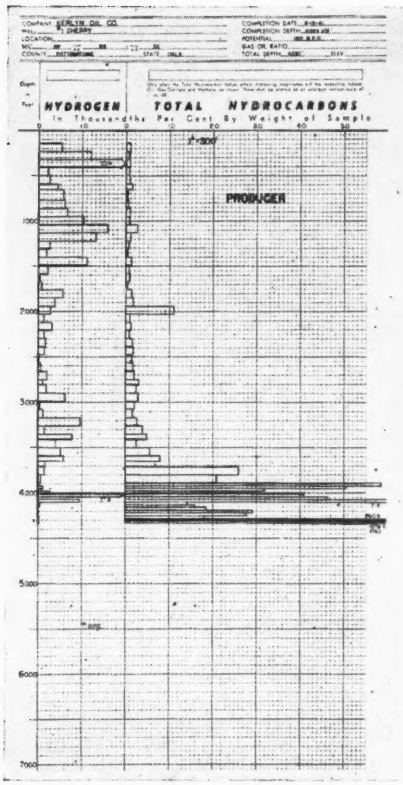


FIG. 3. *Kerlyn Oil Company #1 Cherry*

This is a Chemlog of a producing well in Pottawatomie County, Oklahoma. It exhibits a completely developed Hydrogen pattern at shallow depth. It also shows a well-developed favorable Hydrocarbon pattern which commences to become significant at about 2700 feet. The log indicates two possible productive horizons, the lower one of which produces 180 barrels per day at 4325 feet.

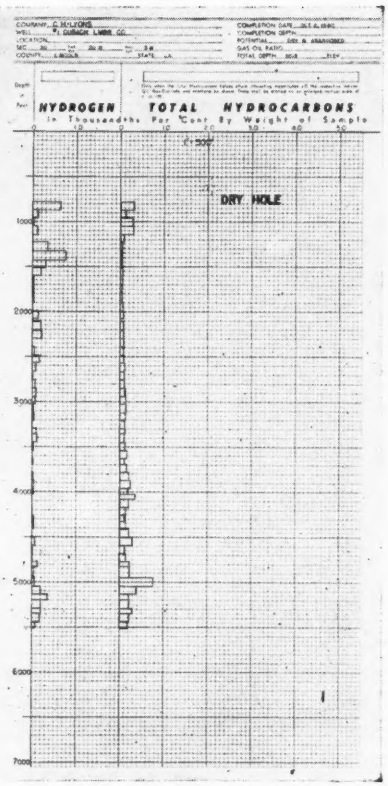


FIG. 4. *C. H. Lyons #1 Dubach Lumber Co.*

This is the Chemlog of a dry hole from Lincoln Parish, in northern Louisiana. The moderately high value at 5000 feet is from a core taken from a sand at that depth which was non-productive, as indicated by the magnitude of the Hydrocarbon value.

No significant Hydrogen values are present, although a few in the upper part of the Chemlog appear so, relatively.

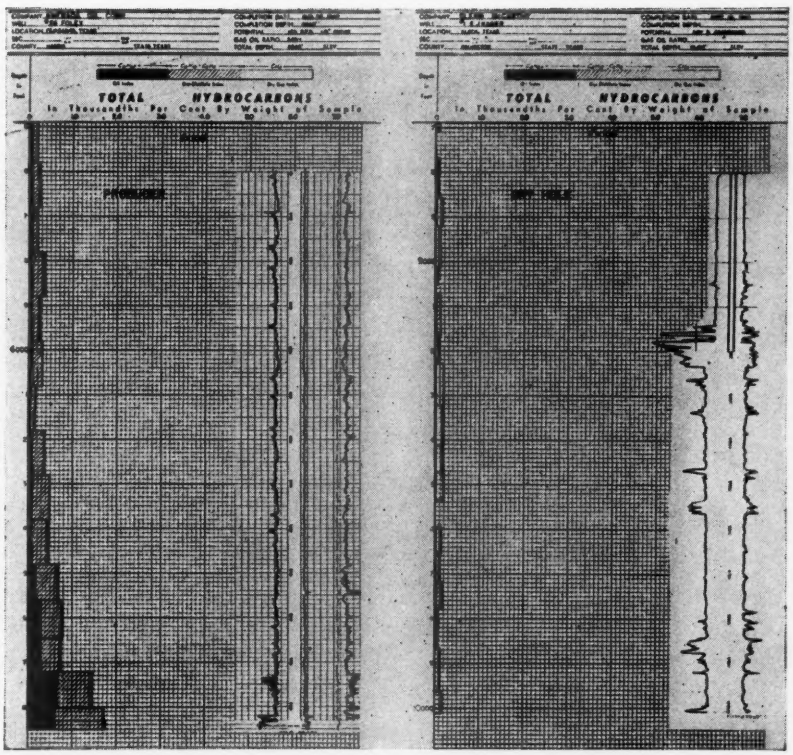


FIG. 5. *Amerada Petroleum Corp. #26 Foley*

This is the first of a group of large-scale Chemlogs. (1 inch per 100 feet) on which the electric logs have been placed for comparison. Note elimination of Hydrogen log and division of total Hydrocarbons as three fractions: Gas, Gas Distillate, and Oil Indices. These are arbitrary but are indicative of the kind of production to be expected.

The Chemlog indicates the producing horizon at 6848 feet, which is not clearly portrayed on the electric log.

FIG. 6. *Glenn McCarthy #1 E. J. Kainer*

This detailed Chemlog of a dry hole in Galveston County, Texas, is also compared with the Electric log. Considerable money could have been saved on this well if it had not appeared advisable to the operator to ignore the information on the Chemlog and core a large part of the section shown on this slide. Furthermore, the well would not have been carried beyond 9500 feet if the prediction value of the Chemlog had been considered.

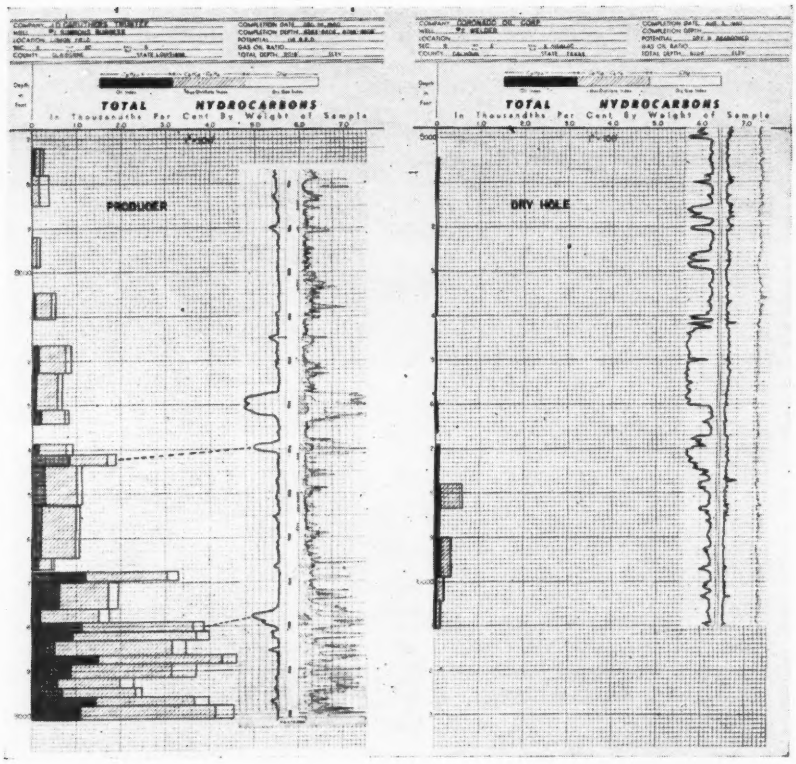


FIG. 7. *J. D. Caruthers Trustee #1 S. Burgess*

Detailed Chemlog of a deep test in the Lisbon Field, Claiborne Parish, Louisiana, opening up a new deep producing sand at 8766 to 8806 feet. A series of potential producing horizons are seen on this Chemlog which correlate with the electric log. The only two tested, 8393 to 8408 feet, and 8766 to 8806, produce. Total oil production is 114 barrels per day with gas in excess of 70 m.c.f. This Chemlog serves the dual purpose of showing zones worthy of testing and also of giving favorable patterns suggesting deeper production.

FIG. 8. *Coronado Corp. #2 Welder*

This is the Chemlog of a dry hole outside the producing limits of the Jay Welder (Duck Bay) Field. Note the low values in the sandy parts of the section. The well shows a moderate value near the point where the producing sand should be. This is a typical example of a dry hole, although the value near 5800 feet might suggest an horizon which is productive elsewhere.

ADVERSE FACTORS

Several factors affect the results obtained in the analysis of well cutting. One of the most important of these is the ability of the sample to retain the desired constituents; this affects the magnitudes of the values on the Chemlog, but fortunately, is small in comparison with the effect caused by significant concentrations of Hydrocarbons. Changes in values due to retentive ability of the sample are of the order of 3 to 2 or 2 to 1, while the range from saturated to non-saturated formations is of the order of 20 to 1 and greater. Other factors include poor samples from badly caving holes, difficulty in collecting extremely fine sand samples, and high values obtained from oil shales which are non-productive because of insufficient porosity and permeability.

CONCLUSIONS

The Chemlogs illustrated exhibit certain properties which determine their usefulness. First of all it is clear that recognizably high Hydrocarbon values occur at the productive horizons in a well. As the Chemlog is made while drilling is carried on it may indicate:

1. When and where to core, thus saving unnecessary coring.
2. Whether electrical, side wall core, drill-stem or other testing is needed.

This detection or location of producing horizons means that unsuspected pay zones will not be passed through. It also suggests that gas may be distinguished from oil production.

Another characteristic of the displayed Chemlogs is the shape of the depth concentration pattern. This property may be used for prediction which gives rise to another set of applications:

1. When to drill ahead on a well that might otherwise be abandoned before it reaches production.
2. When to abandon a well that might be uselessly deepened.
3. When a dry hole or edge well may be close to pay laterally.

These advantages suggest that the Geochemical Well Log will be used as a guide in drilling operations on wildcat wells; and that it will also be used in conjunction with other methods after the well has reached its final stages, and a decision is being made whether to abandon or set casing and test. The method is still subject to development and other practical applications should be discovered as more experience is gained.

DISCUSSIONS AND COMMUNICATIONS

REPORT ON ORGANIZATION OF THE SOUTHERN SEISMIC WELL SHOOTING ASSOCIATION

One of the fundamental assumptions which has been used to convert the results of a reflexion seismograph survey into a subsurface structural picture has been that the vertical distribution of the velocity remained constant over the area of the survey, and that any differences in reflexion times to a given layer could be interpreted as indicating differences in depth to that layer. Fortunately, this assumption has been quite satisfactory in many cases, especially when the object of a survey has been to locate fairly pronounced structures. The actual velocity law used was sometimes just an asusmption, or may have been based on results of refraction shooting, or computed from the Δt's of the reflexion survey itself. It was early recognized that such velocity information was not entirely satisfactory, and well geophones were designed which made it possible to carry out velocity surveys in wells. As it becomes increasingly important to map structures with small closure, it becomes increasingly necessary to know the actual velocities which should be used in seismic interpretations.

In both the Mid-Continent and California areas, associations were formed for the purpose of making such velocity surveys on a cooperative basis, and it was learned in California that in some places the lateral changes in velocity were of such a magnitude that they had a profound influence on the subsurface interpretation of seismic results. We can be sure that such conditions exist in some other areas, but they can be definitely located and corrections made for them only on the basis of extensive well velocity surveys.

Last year a group of representatives from various oil companies began a series of meetings in Houston, which culminated in the formation of the Southern Seismic Well Shooting Association. The fundamental purpose of this association is to promote the carrying out of cooperative velocity surveys in wells in the southern United States, and to promote the sale and exchange of existing velocity surveys among members, and to encourage the use of standard forms for recording such surveys. Some companies have previously shared some of their velocity surveys with others on a cooperative basis, but there was no standard procedure for this. There are 17 charter members in the Association, and new members may be elected by a two-thirds vote. We are anxious to have any oil or geophysical company which is interested in the interpretation of seismic surveys in the southern and southwestern states become a member, and I will be glad to send a copy of the regulations to anyone who is interested. The Association is a nonprofit one, handles no money, and there are no membership fees. Each well shot is treated as a separate project. In simple terms, if a member of the Association desires to shoot a well or desires that one be shot, he gives the information to the secretary, who in turn notifies all the members of the Association and finds out which ones desire to participate in the survey, and which one could arrange to shoot the well in case the original proposer is not in a position to do it. There are several contractors in the Association who are equipped to shoot wells. The secretary furnishes a list of the participants to the company shooting the well, and this company bills the participants directly for their share. If a company declines to participate in such a survey at the time it is made, but decides later that they desire it, they can obtain it by paying the original share plus 50%. This money is distributed among the original participants. New members can obtain data from old surveys on the same basis.

It is anticipated that most well velocity surveys will cost less than $1,000.00 but occasionally one may cost $2,000.00 or more if conditions are especially unfavorable. I hope that we will have enough participants in each velocity survey, so that the price per survey will be low enough to induce every company to participate in practically all of the surveys, even though they may not be directly interested in the area concerned at the time the survey is made.

Further details can be found in the regulations of the Association.

There are plenty of arguments to justify extensive well velocity surveys. I am sure that most of you who have dealt with seismic surveys have experienced trouble when you have finally connected various separate surveys made at different times by different parties using different velocities. You can, of course, recompute the results with one velocity, but without adequate control from well velocity surveys you may still have to do the job over again at a later date. We ought to have a velocity survey in every deep, important wildcat well, and I hope that the various seismologists will cooperate towards that end. There will, however, always be certain wells which can not be shot for one reason or another. In areas where we may eventually find pronounced lateral changes in the velocity a closer spacing of well surveys may be necessary than in areas where the lateral changes are very gradual and regular. We will undoubtedly look back at certain areas and say that the velocity surveys only confirmed our previous ideas, but we will find other areas where pronounced lateral variations in velocity may account for disparities between seismic results and well correlations which might have been formerly interpreted as indications of faulting. I feel certain that, as a whole, velocity surveys will repay their cost many times.

The fundamental problem of making a velocity survey in a well is fairly simple. Charges are set off in one or more shot holes located some 500 to 1,000 feet from the well, and the resulting waves recorded on a geophone lowered to various depths in the well. The shots should be fired below the base of the weathered layer, the depth to which should be determined in most cases by recording a series of uphole times with shots at various depths in the shot holes. In some cases a short refraction profile may be satisfactory for this. It is absolutely essential that the timing device used be checked against some standard, such as the Arlington time signals, since wells shot with various instruments must be compared to make a regional velocity study.

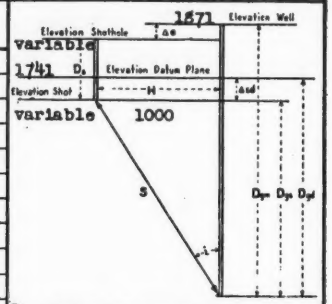
Assuming that a well velocity survey is carried out with sufficient accuracy and care, the next important point is the manner of working up the results. In order to make any sort of detailed comparison of velocity surveys in different wells, it is necessary that the results be worked up in the same manner, and even plotted on standard scales. Fig. 1 shows a form which has been used extensively in California and which is already used by some companies here, and I propose its general adoption for wells shot under the auspices of the Southern Seismic Well Shooting Association. This form contains all the essential information from a velocity survey, and from it the time-depth, interval velocity and average velocity curves can be plotted on any desired scale. I have prepared a number of transparent Van Dyke positive prints of this form from which other prints can be made and I will be glad to furnish anyone interested with one of them.

I have filled in two lines on the copy shown in Fig. 1 to indicate how it is used.

The first seven columns give, in order, the record number, the shot hole number, the depth of the well geophones, the depth to the shot hole, the uphole time at the shot hole, the uphole time at the well, and the travel time to the well geophone. The uphole time at the well may be useful to check a questionable timing break. It is a desirable practice

Shothole information:- Elevation, Distance & Direction from Well			Company	Well	Elevation	Total Depth	LOCATION			
1	1841	1000' E.					Coordinates.	Section, Township, Range.	County.	Area or Field.
2	1866	1000' W.								
3										

Record Number	Shothole Number	D_{gm}	D_s	t_{us}	t	T	D_{gs}	H	tan i	cos i	T_{gs}	T_{gd}	D_{gd}	ΔD_{gd}	ΔT_{gd}	V_i Interval Velocity	V_a Average Velocity
2	2	2000	129	.025	.087d	.179 s	1866	1000		.88139	.1578	.1581	1870	500	.0363	13,780	11,820
19	2	2500	125	.025	.088d	.211 s	2370	"		.92135	.1944	.1944	2370				12,190



D_{gm} = Geophone depth measured from well elevation.
D_{gs} = " " " shot "
D_{gd} = " " " " datum "
D_s = Depth of shot
H = Horizontal distance from well to shotpoint.
S = Straight line travel path from shot to well geophone
t_{us} = Uphole time at shotpoint.
T = Observed time from shotpoint to well geophone.
Δe = Difference in elevation between well & shotpoint
Δsd = " " " " shot & datum plane
$D_{gs} = D_{gm} - D_s \pm \Delta e$; $\tan i = \frac{H}{D_{gs}}$
T_{gs} = cos i T = Vert. travel time from shot elev. to geophone
$T_{gd} = T_{gs} \pm \frac{\Delta sd}{V}$ " " " " datum plane " "
$D_{gd} = D_{gs} \pm \Delta sd$ = Vert. distance " " " " "
V_i = Interval velocity = $\frac{\Delta D_{gd}}{\Delta T_{gd}}$
V_a = Average " = $\frac{D_{gd}}{T_{gd}}$

Surveyed by:.....

Date:.....

Weathering Data.

V = 11,450 ft./sec.

Casing Record_____

to add the letters *d* or *u* to indicate the direction of the kick. These first seven columns, together with the information contained at the heading of the sheet, are all that is necessary to work up the velocity survey except a note about the velocity which should be used to correct to datum plane, and this can be placed under "weathering data" at the right.

T is multiplied by cos i to give T_{gs}, the vertical travel time from the shot elevation to the well geophone. At this point it is necessary to correct the results to a datum plane, and this datum plane can be most conveniently taken at the average depth of the shots, provided that this is below the weathered layer. Some people prefer to use the base of the weathered layer as a datum plane, and this is also satisfactory. T_{gd}, the vertical travel time from the datum plane to the well geophone, is obtained from T_{gs} by adding or subtracting the difference in elevation between the shot and the datum plane divided by the proper velocity, as noted under "weathering data." This value, plotted against D_{gd}, the vertical distance from the well geophone to the datum plane, gives the vertical time-depth graph, and from these two values the average velocity can be computed.

The next two columns give the difference in depth to the well geophone for two adjacent measurements, and the difference in vertical time for these two measurements. The interval velocity can be computed from these two values.

There will be technical problems which will arise in connection with correcting for lateral velocity changes, but they can be solved if the proper material is available. We can expect improvements to be made in the technique of well shooting. For instance, members of the Shell research staff are working on the problem of using two well seismometers separated by 500 feet, which would give more reliable interval velocities and would also give better checks on the whole survey. I hope that anyone who is interested in velocity surveys will give us their full cooperation, and that those who have not been interested heretofore will realize that this is a very fruitful field in which to work.

L. K. MOWER

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Shell Bldg.
Houston, Texas.

PATENTS*

ELECTRICAL PROSPECTING

U. S. No. 2,234,956, S. Bilinsky. Iss. 3/18/41, Appl. 8/25/38. Assign. E. E. Rosaire.

Exploration With Electric Impulses—Current and potential electrode pairs are laid out at right angles for zero mutual inductance between conductors while making A.C. or transient measurements in surface prospecting.

U. S. No. 2,237,643, S. S. West. Iss. 4/8/41, Appl. 9/29/36. Assign. E. E. Rosaire.

Method of Subsurface Prospecting—A.C. is applied to current electrodes. Wave form of the voltage picked up by potential electrodes is compared with another voltage of variable wave form which is adjusted until it cancels the earth potential. Rectangular form is preferred.

U. S. No. 2,240,520, M. Schlumberger. Iss. 5/6/41, Appl. 5/16/39.

Method and Apparatus for Electrical Underground Prospecting—Variations of the natural telluric currents are recorded over a period of time at two calculations. Electrodes at right angles at each location are used to obtain two-component polar type records which are compared to determine the relative magnitudes and directions of the current at different points at corresponding instants.

U. S. No. 2,241,623, D. Silverman and P. F. Hawley. Iss. 5/13/41, Appl. 10/23/39. Assign. Stanolind Oil and Gas Company.

Electrical Surveying—Electrical discontinuities in the vicinity of a current electrode are detected by the use of potential electrodes disposed symmetrically about the current electrode.

U. S. No. 2,242,312, L. Machts. Iss. 5/20/41, Appl. 5/28/38.

Geophysical Apparatus—Radio transmitter and receiver with loop antennae are supported at opposite ends of a rack which is carried about to locate subterranean deposits.

U. S. No. 2,243,428, P. W. Klipsch and S. Bilinsky. Iss. 5/27/41, Appl. 10/8/37. Assign. E. E. Rosaire.

Electrical Prospecting—Earth impedance between two electrodes is used as one arm of a bridge circuit which is balanced by inserting a variable impedance network in another arm of the bridge. Square waves are preferred, and residual wave shapes may be observed as an indication of earth structure.

GRAVIMETRIC PROSPECTING

U. S. No. 2,239,049, T. S. Morris. Iss. 4/22/41, Appl. 4/25/38.

Gravity Meter—A weight is supported in equilibrium position by the force of a solenoid in a permanent magnetic field. Solenoid current indicates gravity value.

U. S. No. 2,243,746, D. H. Clewell. Iss. 5/27/41, Appl. 2/21/40. Assign. Socony-Vacuum Oil Company, Inc.

* Quarterly listings provided by Gary Muffly, Gulf Research & Development Co

Gravity Meter—Gravimeter mass carries a series of parallel plates at each end whereby electrostatic forces may be applied to help damp its motions and bring it to a standard position.

U. S. No. 2,243,747, D. H. Clewell. Iss. 5/27/41, Appl. 2/21/40. Assign. Socony-Vacuum Oil Company, Inc.

Gravity Meter—A conductive damping disc placed parallel and concentrically between the flat annular pole faces of an A.C. electromagnet brings a gravimeter mass into standard position. A.C. is turned off after the mass is unclamped and stabilized.

U. S. No. 2,243,748, D. H. Clewell. Iss. 5/27/41, Appl. 2/21/40. Assign. Socony-Vacuum Oil Company, Inc.

Gravity Meter—Electromagnetic repulsion of a conductive member is used to bring a gravimeter mass to standard position. A.C. current required for balance is taken as indication of the gravity value.

U. S. No. 2,243,749, D. H. Clewell. Iss. 5/27/41, Appl. 2/21/40. Assign. Socony-Vacuum Oil Company, Inc.

Gravity Meter—Gravimeter mass is brought to null position by means of electrostatic forces. Potential required indicates gravity value.

U. S. No. 2,243,750, D. H. Clewell. Iss. 5/27/41, Appl. 3/6/40. Assign. Socony-Vacuum Oil Company, Inc.

Gravity Meter—Gravimeter mass is placed on a rod which is supported at an acute angle to the horizontal by means of a horizontal leaf spring at its lower end and a horizontal coil spring at its upper end.

GEOCHEMICAL PROSPECTING

U. S. No. 2,234,637, M. S. Taggart, Jr. Iss. 3/11/41, Appl. 7/22/39. Assign. Standard Oil Development Company.

Oil Prospecting Method—Hydrocarbon-consuming bacteria are planted in soil samples which are removed after a period of time to determine the propagation of the bacteria as an indication of oil or gas.

SEISMOGRAPH PROSPECTING

U. S. No. 2,235,089, N. R. Sparks. Iss. 3/18/41, Appl. 1/14/39. Assign. Stanolind Oil and Gas Company.

Modulated Steady State Reflection Seismic Surveying—Frequency of continuous seismic waves is varied linearly with time and beat frequencies are detected corresponding to differences between waves received over different paths.

U. S. No. 2,238,023, P. W. Klipsch. Iss. 4/8/41, Appl. 3/23/39. Assign. E. E. Rosaire.

Equalizer—Bridged-T network of constant-impedance type is used for high and low frequency equalization. Resistors are varied to regulate the attenuation.

U. S. No. 2,238,116, D. A. Kelly. Iss. 4/15/41, Appl. 8/10/38. Assign. Stanolind Oil and Gas Company.

Method and Apparatus for Producing Constant Amplitude Motion—Shaking table for seismometers comprises a resiliently-supported mass, a pendulum suspended from the mass, and an eccentric rotating on an axis parallel to the axis of oscillation of the pendulum and passing through its center of percussion so that only the vertical component of force acts on the mass.

U. S. No. 2,241,428, D. Silverman. Iss. 5/13/41, Appl. 6/28/38. Assign. Stanolind Oil and Gas Company.

Apparatus for Underwater Seismic Surveying—Seismometers are floated in a body of water and are held in position by cables and anchors. Shot is fired at the bottom of the body of water.

U. S. No. 2,241,874, T. Zuschlag. Iss. 5/13/41, Appl. 2/24/39. Assign. Lundberg Exploration S.A.

Method for Geophysical Exploration—Continuous-wave seismic prospecting method measures relative phases and amplitude ratios between various pairs of points.

U. S. No. 2,243,729, L. G. Ellis. Iss. 5/27/41, Appl. 8/20/38. Assign. Sun Oil Company.

Method for Analysis of Seismographic Records—Method of combining variable-density seismograph traces provides for systematic variation of slit displacements to produce a combined trace in which the components are kept in phase throughout the record.

U. S. No. 2,243,730, L. G. Ellis. Iss. 5/27/41, Appl. 8/18/39. Assign. Sun Oil Company.

Apparatus for Analysis of Seismographic Records—Apparatus for combining variable-density seismograph traces provides for systematic variation of slit displacements to produce a combined trace in which the components are kept in phase throughout the record.

WELL LOGGING

U. S. No. Re.21,797, J. J. Jakosky. Iss. 5/13/41, Appl. 4/12/38. Assign. Schlumberger Well Surveying Corp.

Method and Apparatus for Alternating-Current Investigation of Uncased Drill Holes—A. C. Well Logging using potential, phase, power loss, dielectric constant or impedence measurement. Measurements may be made at different frequencies. Electrode areas may be made large.

U. S. No. 2,232,476, O. F. Ritzmann. Iss. 2/18/41, Appl. 11/27/39. Assign. Gulf Research & Development Co.

Method of and Apparatus for Measuring Depths in Wells—Depths to liquid surface, tubing collars and other discontinuities in wells are recorded by means of an abrupt sound pulse and high frequency echo-recording equipment.

U. S. No. 2,233,420, E. G.Leonardon. Iss. 3/4/41, Appl. 6/4/37. Assign. Schlumberger Well Surveying Corp.

Method of and Apparatus for Exploring Drill Holes—Holes not containing conductive fluid are electrically logged by using electrodes that rub on the wall. Wire brushes or porous bags containing electrolyte may be used for electrodes.

U. S. No. 2,233,992, R. D. Wyckoff. Iss. 3/4/41, Appl. 1/3/38. Assign. Gulf Research & Development Co.

Method of and Apparatus for Surveying Wells—Acoustic well logging. Sharp individual pulses are used to measure velocity at various levels in a well. Pulses may be repeated each time a preceding pulse is received and the frequency of pulses used to indicate the velocity.

U. S. No. 2,235,064, R. T. Cloud. Iss. 3/18/41, Appl. 7/16/38. Assign. Stanolind Oil and Gas Company.

Determination of Densities of Fluids in Wells—Density of well mud is logged by measuring either its pressure gradient or the net weight of a body submerged in it. Values are indicated telemetrically at the surface.

U. S. No. 2,236,668, L. W. Blau and R. R. Thompson. Iss. 4/1/41, Appl. 5/11/38. Assign. Standard Oil Development Co.

Method and Apparatus for Logging Wells—Well logger makes simultaneous measurements of electrical transients and spontaneous potentials with a single galvanometer.

U. S. No. 2,239,466, J. Neufeld. Iss. 4/22/41, Appl. 5/7/37. Assign. Well Surveys, Inc.

Method of and Apparatus for Electrical Investigation of Drill Holes—Electrical transient well logger records the peak values of each transient and of its time derivative.

U. S. No. 2,241,154, J. Neufeld. Iss. 5/6/41, Appl. 10/1/38. Assign. Well Surveys, Inc.

Well Surveying Method and Apparatus—Well is logged using luminous fluorescence to detect the presence and location of oil.

U. S. No. 2,242,161, L. F. Athy and H. R. Prescott. Iss. 5/13/41, Appl. 5/2/38. Assign Continental Oil Company.

Method of Logging Drill Holes—Acid or other chemical reagent is introduced into a bore hole and selective reaction on various strata is observed by logging the well temperature.

U. S. No. 2,242,612, E. G. Leonardon. Iss. 5/20/41, Appl. 5/25/37. Assign. Schlumberger Well Surveying Corp.

Method for Determining the Beds Traversed by Drill Holes—Well temperature is logged after continued flushing with liquid of a temperature differing from that of the formations. Resistance of the liquid is measured as an indication of its temperature.

U. S. No. 2,244,484, R. F. Beers. Iss. 6/3/41, Appl. 5/7/38.

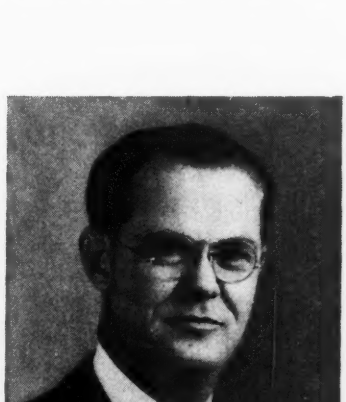
Method of and Means for Analyzing and Determining the Geologic Strata below the Surface of the Earth—Acoustic impedance of well formations is studied by placing a sound source in the well and driving it electrically at different frequencies while observing its electrical impedance.

CONTRIBUTORS*

W. T. BORN
Past President

W. T. BORN received his B.S. degree from the University of Chicago in 1925. He was employed by the Geophysical Research Corporation as physicist in December of that year. In 1932 he was appointed Director of the Laboratory in the same company, which position he still holds. Mr. Born has been closely associated with the design and development of instruments used in the seismic and electrical exploration methods and has devoted much time to field and laboratory experimentation in those fields. He served as Vice President of the Society of Exploration Geophysicists during 1938 and 1939 and as President in 1940.

H. E. BANTA received his B.A. degree from the Rice Institute in 1927, and his Ph.D. degree from Rice in 1932. He became engaged in geophysical work in 1927, when he was connected with the Geophysical Research Corporation. In 1933 he became associated with the Independent Exploration Company, by whom he is still employed. His position has largely been that of party chief and seismologist, but recently he has been engaged in instrument research at Kannenstine Laboratories. He is a member of the American Physical Society, the A.A.P.G., and the Society of Exploration Geophysicists.



H. E. BANTA

* GEOPHYSICS is initiating a new Section in which a photograph of contributors to the Journal together with a brief biographical sketch will be published concurrently with publication of the papers. In this way it is hoped that readers of the Journal may secure, in some measure, the feeling of personal contact and acquaintance that accompanies the presentations at our Annual Meetings. It is believed that our readers will appreciate this introduction to the authors who are contributing to the activities of our Society and to the development of the geophysical art.—Editor.

F. F. CAMPBELL graduated from Haverford College with a B.S. degree in 1926, and from Graduate School of Business Administration, Harvard University, with a M.B.A. degree in 1931. He was employed by the Geophysical Research Corporation, Tulsa, Oklahoma, June, 1926 to September, 1928; June, 1929, to September, 1930; and continuously from March, 1933. His present occupation is chief of seismograph field party. He is a member of the Society of Exploration Geophysicists.

F. F. CAMPBELL

L. L. NETTLETON

LEWIS L. NETTLETON received his B.S. degree from the University of Idaho in 1918 and his Ph.D. degree from the University of Wisconsin in 1923. From 1923 to 1928 he was engaged in electrical work in the research department of the Union Switch & Signal Company at Swissvale (Pittsburgh), Pennsylvania. Since 1928 he has been in the research laboratory of the Gulf Oil Corporation where he has had charge of the interpretation and mapping of gravity results (torsion balance, pendulum, and gravimeter). Also he has done some work in dynamic geology which is best known through his fluid mechanical concept and fluid models of the formation of salt domes. For some ten years he has been a member of the faculty of the University of Pittsburgh and has given a course of lectures on geophysical prospecting, the material of which was recently published as "Geophysical Prospecting for Oil." He is a member of the American Physical Society, A.A.P.G., American Geophysical Union, A.A.A.S., Pittsburgh Physical Society, and a member of the Society of Exploration Geophysicists.

H. R. PRESCOTT

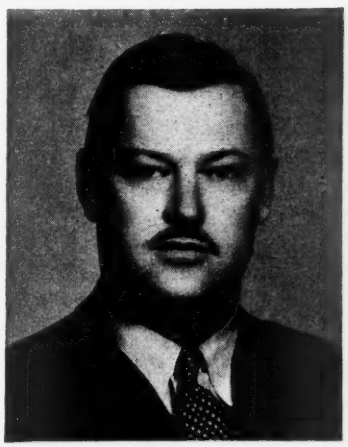
H. R. PRESCOTT received his B.S. degree in E.E. from the University of Kansas in 1927. He has been connected with geophysical work since 1927 when he was employed by the Marland Oil Company in connection with pendulum development. Employment continued with the Continental Oil Company, following its merger with the Marland Oil Company, in the capacity of development Geophysicist. In 1939 he became Assistant Chief Geophysicist of Continental Oil Company by whom he is still employed. He is a member of the Society of Exploration Geophysicists.

W. R. RANSONE received his B.S. degree in mathematics from Southern Methodist University in 1930, and his M.A. in physics from the University of Texas in 1931. He has been engaged in geophysical work since 1926 when he was connected with the Geophysical Research Corporation. In 1930 he became associated with Geophysical Service, Inc., by whom he is still employed. Mr. Ransone's work has been primarily in the field of seismograph exploration, with several years' experience abroad, particularly in South America and Canada. He has recently been associated with the development of Geochemical Prospecting. He is a member of A.I.M.E., Institute of Petroleum A.A.P.G., A.A.A.S., and the Society of Exploration Geophysicists.

W. R. RANSONE

N. RICKER

NORMAN RICKER received his B.A. degree in 1916, and his M.A. in 1917, and his Ph.D. in 1920—all from The Rice Institute. After an instructorship in Physics at Rice and two years with the Bell Telephone laboratories in New York City, Dr. Ricker entered actively in the field of geophysics. Employed in 1923 by the Humble Oil and Refining Company, he organized and directed their Geophysical Department, contributed to the development of refraction seismic prospecting, and introduced the use of radio in such operations. Resigning from the Humble Company in 1925, he worked independently in geophysics, and in 1927 was engaged by the Hughes Tool Company to develop the Plunger Lift. In 1938 Dr. Ricker accepted a position as Senior Geophysicist with the Carter Oil Company, where he is now employed at their Research Center in Tulsa. He is engaged in further development of seismic processes. Among Dr. Ricker's accomplishments at the telephone laboratories was the invention of the paper cone type loud-speaker, which displaced the horn type. He holds memberships in the American Physical Society, American Math. Society, Acoustical Society of America, Seismological Society of America, American Geophysical Union, A.A.A.S., The Houston Philosophical Society, and the Society of Exploration Geophysicists.



J. H. WILSON

JOHN H. WILSON received his E.M. degree from the Colorado Schoo! of Mines in 1923. From that time until 1926 he was engaged in surface geologic mapping, sample examination and core drill supervision for the Midwest Refining Company, Denver, Colorado. From 1926–1927 he was in charge of geophysical and core drill work for the Pan-American Petroleum and Transport Company at Tampico, Mexico; in 1928 and 1929 he was assistant professor of geophysics at the Colorado School of Mines; from 1930 to 1933 he was a consulting geophysicist and geologist for various firms and individuals; from 1933 to the present he has been associated with the Independent Exploration Company and its affiliates. His work has been primarily in the correlation of geological and geophysical data. He is a member of the A.A.P.G., associate member of the A.I.M.M.E., and a member of the Society of Exploration Geophysicists.

THE SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualification of these nominees, he should send it to the Secretary within thirty days. (Names of sponsors are placed beneath the name of each nominee.)

ACTIVE

John Baird
C. A. Heiland, Dart Wantland, J. E. Hawkins

Lavon Couch Dodd
L. G. Ellis, W. E. Hollingsworth, H. W. Rose

Russell Carter Doolittle
John J. Rupnik, Beno Gutenberg, Hugo Benioff

✓Norman Jared Lea
George D. Mitchell, Jr., Roy L. Lay, M. L. Benke

Fielding L. Mitchell
R. W. Gemmer, George E. Wagoner, A. B. Bryan

✓James Alexander Peoples, Jr.
Maurice Ewing, Hart Brown, J. B. Hersey

Maurice Sklar
F. Goldstone, Leonard F. Uhrig, F. A. Van Melle

Booth Barrington Strange
Henry Salvatori, Dean Walling, M. B. Widess

Archie Carter Swearingen
N. P. Teague, Garvin L. Taylor, R. Clare Coffin

ASSOCIATE

Alejandro Del Rio M.
Dart Wantland, J. E. Hawkins, C. A. Heiland

Howard Minton House
Josiah Taylor, Robert H. Ray, R. L. McLaren

Ralph Harrington Howe
W. O. Bazhaw, W. Lee Moore, Jr., W. Harlan Taylor

Dale Hubart Moose
Cecil E. Reel, Hugh C. Schaeffer, Raymond A. Peterson

Charles Thomas Rankin
Albert Taylor, O. C. Lester, Jr., L. Y. Faust

STUDENT

Leo Jean Goldsmith
C. A. Heiland, Dart Wantland, J. E. Hawkins

PERSONAL ITEMS

(Items intended for inclusion in PERSONAL ITEMS should be addressed to J. F. Gallie, Business Manager, P. O. Box 777, Austin, Texas)

The Petty Geophysical Engineering Company in May invited the members of the senior course in Geophysics at the University of Texas to San Antonio for an inspection tour of the Petty Laboratory. LEONARD T. ALLEN and other members of the technical staff served as hosts for the occasion. Following the tour, a dinner was held in the evening for the students and for the Petty geophysicists and their wives. On the preceding day, Mr. Allen discussed "The Practical Side of Petroleum Geophysics" before the class.

Captain GEORGE B. KAISER has been transferred to Long Branch, New Jersey, where he may be addressed at 374 Sairs Avenue.

O. F. VAN BEVEREN is with N. P. P. M., Paleisweg 33, Medan, Sumatra, N. E. I.

CECIL E. REEL is temporarily located at P. O. Box 255, Durant, Oklahoma.

DANIEL SILVERMAN has recently been appointed Laboratory Supervisor in charge of all activities of the Joint Geophysical Laboratory of the Stanolind Oil and Gas Company and the Western Geophysical Company in Tulsa, Oklahoma.

P. M. HONNELL has left Dallas and is located at 2102 Driscoll Street, Houston, Texas.

ROLAND F. BEERS advises that the Research Laboratory of the Geotechnical Corporation has been removed from Cambridge to Lincoln, Mass. The postal address, at which Mr. Beers may be reached, is P. O. Box M.

ROBERT BARLING, formerly with the Mott-Smith Corporation, is now with the Western Geophysical Company and is located in Hanford, California.

J. W. DE BRUYN has been transferred from Karachi, India, to Tandjoeng Loentar, Postoffice Moeara Enim, Sumatra, N. E. I.

R. B. MORAN, JR., of the Superior Oil Company, has been transferred from Bakersfield to Route 1, Box 234X, Fresno, California.

MALCOLM S. MORRISON has returned from South America and is located at 338 Emerson, N.W., Washington, D. C.

The Independent Petroleum Association of America has published a booklet entitled "The Problem of the Unnecessary Well." This booklet, which is being widely distributed among oil operators and landowners, considers the petroleum industry's responsibility in the conservation of steel and other vital defense materials.

Captain CHAS. GILL MORGAN of Dallas, Texas, President of the Morgan Engineering Corporation, is now stationed in Washington, D. C. He may be addressed in care of the War Department, Office, Chief of the Air Corps, Washington, D. C., or at Apartment 196, Arlington Village, Arlington, Virginia.

ROY LEE GALLAWAY, of the Texas Company, is now located in Jonesville, Louisiana.

J. E. HAWKINS may be addressed at 1339 South Indianapolis, Tulsa, Oklahoma.

L. C. SPENCER advises that the Shreveport office of the Atlantic Refining Company has been moved to 1001 City Bank Building, Shreveport, Louisiana.

CHAS. F. REED is now Manager of the Houston Sales Office of the Dow Chemical Company, with offices in the Commerce Building in that city.

IRNACK C. DO AMARAL advises that his address is Rua Siqueira Campos 194, Apt. 101, Copacabana, Rio de Janeiro, Brazil.

H. J. MCCREADY, Party Chief with the Mott-Smith Corporation, should be addressed at 4923 Knox Court, Denver, Colorado.

The correct address of NORMAN A. HASKELL is P. O. Box 344, Bass River Postoffice, Cape Cod, Mass.

GEO. C. MCGHEE has left Dallas for an indefinite period to serve in the Office of Production Management, Room 4072, Social Security Building, Washington, D. C.

O. F. SUNDT, former consulting geologist and geophysicist, 1401 Esperson Building, Houston, Texas, is now chief geologist for Texas Gulf Producing Company, Box 2199, Houston, Texas.

W. W. BUTLER, formerly with the Barnsdall Oil Company, is now with the Gulf Research and Development Company, P. O. Box 2038, Pittsburgh, Pennsylvania.

NATHAN C. DAVIES has removed from Fairfield, Illinois, to 2232 East Powell, Evansville, Indiana.

M. H. JAMESON may be addressed at 43 Bellwood Place, Elizabeth, New Jersey.

JOHN M. NASH, on a year's leave of absence from the Shell Oil Company, Inc., is serving as Captain, Signal Corps, C. O. of 304th Signal Aviation Co. His address is Apt. 41, 2311 Morrison Avenue, Tampa, Florida, where he advises that the weather has so far been very delightful.

H. W. STRALEY, III, has left Waco, Texas, to do consulting work in Mining and Petroleum Geology and Geophysics in Princeton, West Virginia. Mr. Straley's office is located in the Seneca Trail Oil Company Building.

J. W. THOMAS, JR., of the Stanolind Oil and Gas Company, has been transferred from Hays to Pratt, Kansas.

CHARLES C. BATES has removed from Rockton, Illinois, and is serving with Battery A, 2nd Obsn. Bn., F. A., Fort Sill, Oklahoma.

R. W. LOHMAN should be addressed at 416 Grand Avenue, South Pasadena, California.

A. P. CRARY, formerly with the Independent Exploration Company in Houston, is now located at the Woods Hole Oceanographic Institution, Woods Hole, Mass., where MAURICE EWING has been for some time past.

B. M. BENCH should be addressed c/o V. G. Bench, 2037 East 70th Street, Chicago, Illinois.

J. H. BURNEY is now with the Standard Oil Company of Venezuela, Caripito, Venezuela, S. A.

HARRY R. IMLE, of the Carter Oil Company, has been transferred from Ardmore, Oklahoma, to Kenmare, North Dakota.

The Department of Geology of the Massachusetts Institute of Technology sponsored the appearance of JOSEPH A. SHARPE of Tulsa, Oklahoma, in three lectures on geophysical exploration which were given at the Institute March 10–12. Dr. Sharpe, who is associated with the joint geophysical laboratory of the Stanolind Oil and Gas Company and Western Geophysical Company as chief physicist, studied with LOUIS B. SLICHTER, Professor of Geophysics at M. I. T., as a General Education Board (Rockefeller Foundation) Fellow in Geophysics in 1934–35.

LEONARD F. UHRIG is serving as Lieutenant with the 20th Ordnance Bn., Pine Camp, New York.

L. F. FISCHER has been transferred from Meridian to P. O. Box 1275, Jackson, Miss. Mr. Fischer is Geophysical Scout with the Gulf Oil Company.

JOHN S. IVY has his offices located in the Niels Esperson Building in Houston, Texas.

DAVE SCHARF, formerly with the Independent Exploration Company, advises that he is now serving with the Contracting Engineers Company of Los Angeles, California.

THOMAS C. BARGER is with California-Arabian Standard Oil Co., Bahrein Island, Persian Gulf. Mail should be sent via Bombay by American President Lines from San Francisco, California.

S. A. WHITE, formerly with Independent Exploration Company, is serving with Co "G," Training Center, Fort Sam Houston, San Antonio, Texas.

L. J. PADDISON, of the Stanolind Oil and Gas Company, has moved fromTyler to Box 242, Greenville, Texas.

A. B. HAMIL, of the Petty Geophysical Engineering Company of San Antonio, recently returned from South America. He is located in Houston at 1449 Mellie Esperson Building, and continues to serve as a supervisor for Petty.

DWIGHT E. WARD, of the Carter Oil Company, has been transferred from Lexington to P. O. Box 621, Kearney, Nebraska.

HENRY SCHOELLHORN, III, who has been with the Gulf Research and Development Company since his graduation from the Colorado School of Mines, is now serving with the 7th Signal Service Co., Fort Sam Houston, Texas.

GIFFORD E. WHITE has entered the employ of the Sperry Gyroscope Company. He may be addressed at P. O. Box 333, Hempstead, New York.

J. P. SCHUMACHER and W. G. SAVILLE advise that offices of the Gravity Meter Exploration Company and Torsion Balance Exploration Company have been moved from 830 Shell Building to 1348 Esperson Building, Houston, Texas.

A. T. SCHWENNESEN is located at 5701 Jackson Street, Houston, Texas, to which address he has moved his office.

G. ROY BROTHERHOOD has left Venezuela and is with the Geological Department of Trinidad Leaseholds Ltd., Pointe-a-Pierre, Trinidad, B. W. I.

C. D. WHITSITT, of the Petty Geophysical Engineering Company, is located in Jonesville, Louisiana, where his postal address is Box 75.

L. J. SMITH, of the Shell Oil Co., Inc., has been transferred from Perry to P. O. Box 536, Tonkawa, Oklahoma.

B. G. HUBNER, JR., of the National Geophysical Company, has been transferred from Forest, Mississippi, to Eldorado, Arkansas.

LAWRENCE A. GOEBEL has left the Carter Oil Company to enter the employ of the Northwest Co., Inc., Box 904, Weyburn, Saskatchewan, Canada.

F. H. AGEE, of the National Geophysical Company, has been transferred from Morgan City to P. O. Box 155, Merryville, Louisiana.

Concluding the series of lectures by prominent geophysicists which was presented before students enrolled in the senior course in Geophysics at the University of Texas, W. M. RUST, JR. presented an interesting resumé of the progress in geophysical methods through the years. L. W. BLAU, who was scheduled to deliver the lectures, was unable to be present.

Any member knowing the whereabouts of Z. A. MITERA, last heard from in Lwow, Poland, before the outbreak of the war, is respectfully requested to communicate with the Business Manager of the Society at P. O. Box 777, Austin, Texas.

CHARLES C. LASH advises that he is now located at 6961 Maple Street, Takoma Park, D. C.